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A STUDY OF IMPACT AND PENETRATION OF THE GATOR MINE IN EARTH MATERIALS

MOBILITY AND ENVIRONMENTAL SYSTEMS LABORATORY
U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a study of the penetration characteristics of an air-delivered, antitank/antivehicle and antipersonnel mine (Gator mine system) as related to variations in mine impact velocity and attitude and changes in soil strength conditions and vegetation. A theoretical study, a field study, and a mapping study were pursued to estimate worldwide mine penetration performance.

The theoretical results are presented in terms of relations of impact velocity (specific velocity ranges) versus maximum depth of penetration and maximum deceleration for various terrain materials. The field study was conducted using an air gun, and the results are presented in NEXT

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terms of relations of impact velocity, depth of penetration, impact angle, impact attitude, and terrain material strength characteristics. In the mapping study the results of the theoretical and field studies were used to estimate the probability of successful emplacement (i. e., in a position suitable for activation) of the mines in any region of the world.

The results obtained from the theoretical study show that, for the normal range of impact velocity, penetration is excessive in clay and sandy clay soils, intermediate in sands, and acceptable in frozen ground and rock. The results obtained from the field study showed that penetration was excessive in lean and fat clay soils when the mine impact angle was 90 degrees. Penetration performance becomes more satisfactory as the impact angle decreases. The results of the mapping study show that a large portion of the world has surface soils too soft to allow acceptable emplacement when the impact angle is 90 degrees. Reducing this angle to 45 degrees will allow acceptable emplacement in many regions.

It is recommended that an earth-clearing charge be incorporated into the mine, and that the cross-sectional shape of the mine be modified so that the mine cannot stand on its edge.

PREFACE

This report documents a study conducted during the period from March 1974 to September 1974 by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under Military Interdepartmental Purchase Requests (MIPR) No. FY7621-74-90081 and FY7621-75-90011 from the Armament Development and Test Center, Air Force Systems Command, Eglin Air Force Base, Florida.

The study was under the general supervision of Messrs W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory (MESL), and W. E. Grabau, Chief, Environmental Systems Division (ESD), MESL. Mr B. O. Benn, Chief, Environmental Research Branch (ERB), ESD, directed the study with the assistance of Mr J. R. Lundien, ERB.

Messrs E. James Lindsey, Jr, and Joseph S. Eken (SD3) managed the program for the Armament Development and Test Center.

This technical report has been reviewed and is approved for publication.

ROBERT F. SMYTH, Colonel, USAF
Director, Munitions System Program Office
Deputy for Armament Systems

JAMES R. LINDSAY, Colonel, USAF
Deputy for Armament Systems

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
Metric (SI) to U. S. Customary		
centimetres	0.3937	inches
metres	3.2808	feet
metres per second	3.2808	feet per second
metres per second per second (g)	3.2808	feet per second per second
grams per cubic centimetre	62.43	pounds per cubic foot
kilograms	2.2046	pounds
kilograms per square centimetre	2048.2	pounds per square foot
cubic metres	35.3144	cubic feet
newtons per square centimetre	0.0145	pounds per square inch
U. S. Customary to Metric (SI)		
tons (short)	0.90718	metric tons

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SECTION I

INTRODUCTION

1. BACKGROUND

a. The Gator mine system (Figure 1) encompasses two visually indistinguishable mines, an antitank/antivehicle (AT/AV) mine and an antipersonnel (AP) mine. In one system being investigated, detonation of the AT/AV mine is initiated by a magnetic sensor and the AP mine by a seismic sensor. The mines are delivered by both rotary and fixed-wing aircraft. The Gator mine system is currently undergoing engineering development in a tri-service program under the Joint Development Plan, Air-Delivered Antipersonnel and Antivehicular Target Activated Munition Systems.

b. The Gator mines are delivered either free-fall or from captive dispensers. At preselected altitudes, the dispensers open and allow individual Gator mines to disperse over a target area. The velocity of the mines at impact with the ground surface is generally between 46 and 76 meters per second. Since they are constructed in a square configuration with rounder corners (Figure 1), uneven air pressure causes the mines to autorotate about a diagonal axis as they fall. Thus, a number of orientations (attitudes) are possible at impact.

c. The Gator mines in their present configuration will not operate effectively if they penetrate the earth's surface and become embedded to a depth of more than a few centimeters. Earth material can collect on the surface of the AT/AV mine and degrade the armor-penetrating capability of the shaped charge. Prototype testing at Eglin Air Force Base, where the mines were dropped from high performance aircraft, has indicated that minimal penetration takes place in the soil at that location. Further study was considered necessary, however, to determine if penetration is a potential problem in other terrain materials. If penetration is excessive, it is likely that the mine performance will be degraded sufficiently to warrant designing an earth-clearing charge into the AT/AV mine.

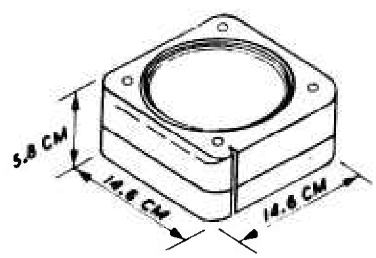
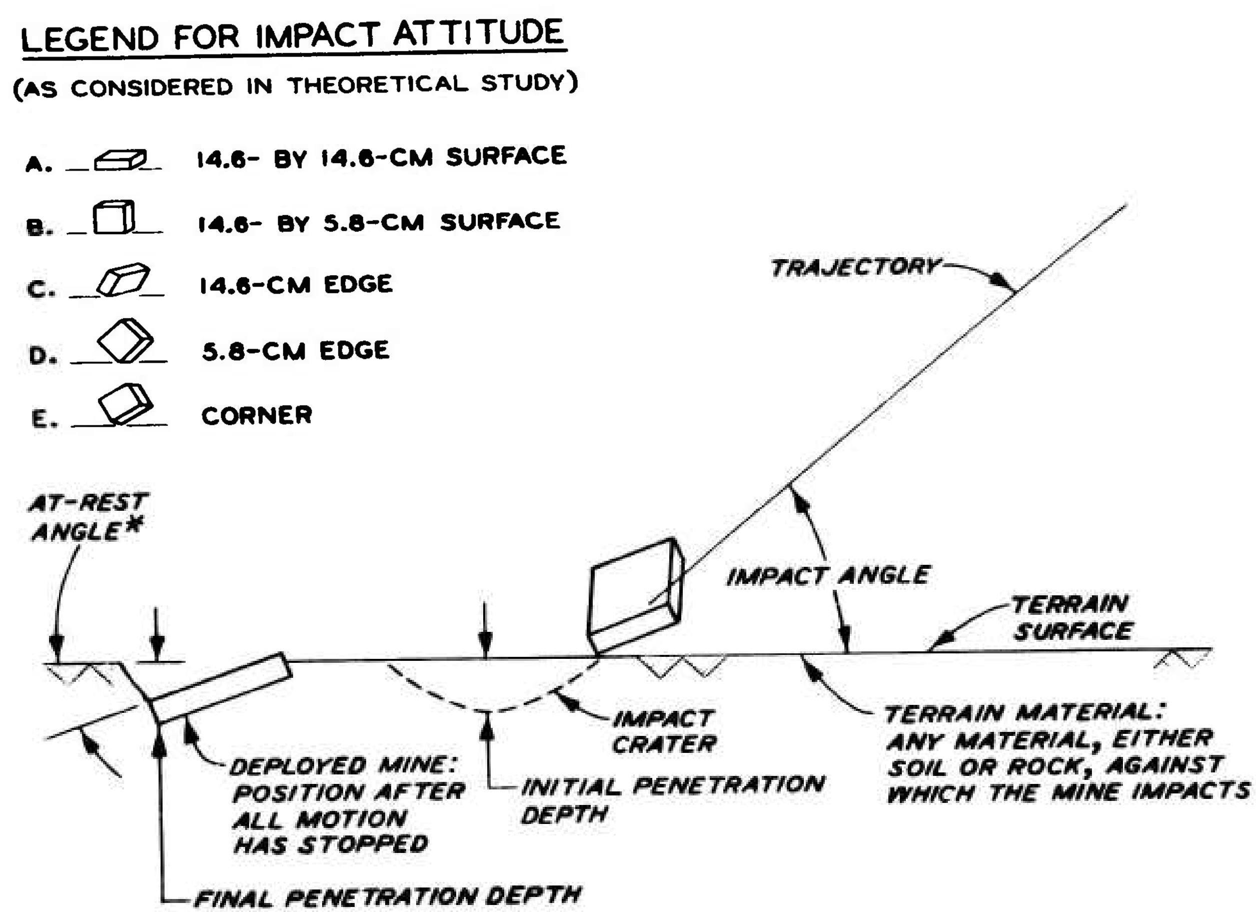


Figure 1. Gator Mine

2. PURPOSE AND SCOPE

a. The purpose of this study was to determine by computer modeling and field tests the penetration characteristics of the Gator mines in various terrain materials (soils and rocks) at various impact attitudes (orientations) over a range of impact velocities. These characteristics were then used to estimate the penetration performance of the Gator mine in world environments. Conditions affecting mine implantation that were addressed included velocity of the mine at impact, impact angle, impact attitude (point of initial contact), soil type and strength, and vegetation conditions (Figure 2). The results of this study are intended to be used in follow-on studies to determine if a requirement exists for incorporating an earth-clearing charge into the design of the Gator AT/AV mine.



*At-Rest angle is the angle formed between a 14.6- by 14.6-cm face and the surface. If the mine is lying flat on the surface, the at-rest attitude is 0 degree; if standing on edge, the at-rest attitude is 90 degrees.

Figure 2. Definitions

b. Results of the theoretical penetration calculations (including maximum deceleration information) are given in Section II; results of the field tests are given in Section III; worldwide penetration performance is estimated in Section IV; and conclusions and recommendations are given in Section V. Except where specifically noted, the terms mine and Gator mine in this report refer to the AT/AV and AP mines interchangeably.

SECTION II

THEORETICAL CALCULATION OF PENETRATION CHARACTERISTICS

1. DESCRIPTION OF MODEL AND TARGET MATERIALS

a. A computerized mathematical model used by the U. S. Army Engineer Waterways Experiment Station (WES) to predict the penetration of projectiles into earth materials was used in the theoretical calculation of the penetration characteristics of the Gator mine. The model is based on the theory of cavity expansion in an elastic-plastic, strain-hardening, locking medium and has been used successfully in other studies of penetration of rigid objects into ice, frozen ground, sand, and clay (References 1, 2). The theory was first used by Goodier (Reference 3) for penetration analysis and later modified by Ross and Hanagud (Reference 1) to include the compressibility of the target materials. A brief description of equations upon which the WES computer model is based is given in References 4, 5, and 6. References 4 and 5 discuss the application of the model to the study of mine projectile implantation into earth materials, and Reference 6 addresses the implantation characteristics of an air-delivered seismic intrusion detector (sensor) into earth materials.

b. The input parameters required to run the model are as follows:

(1) Initial Young's modulus of elasticity (E), kg/cm^2

(2) Strain-hardening modulus (E_t), kg/cm^2

References

1. Ross, B., and Hanagud, S., "Penetration Studies of Ice with Application to Arctic and Subarctic Warfare," Final Report, Sep 1969, Stanford Research Institute, Menlo Park, Calif., prepared for Submarine Arctic Warfare and Scientific Program, Naval Ordnance Laboratory, Silver Springs, Md., and Office of Naval Research, Washington D. C., under Contract N000014-68-A-0243.

2. Rohani, B., "High-Velocity Fragment Penetration of Soil Targets," Proceedings of the Conference on Rapid Penetration of Terrestrial Material, Texas A&M University, College Station, Tex., Feb 1972.

3. Goodier, J. N., "On the Mechanics of Indentation and Cratering in Solid Targets of Strain-Hardening Metal by Impact of Hard and Soft Spheres," Technical Report 002-64, Jul 1964, Stanford Research Institute, Poulter Laboratories, Menlo Park, Calif.

4. Rohani, B., "Theoretical Study of the Penetration of an Antipersonnel Mine Projectile into Earth Materials," Miscellaneous Paper S-72-33, Aug 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. Rohani, B., "Theoretical Study of Impact and Penetration of a Remotely Emplaced Antitank Mine Projectile into Earth Materials," Miscellaneous Paper S-73-58, Jun 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

6. West, H. W. and Rohani, B., "Effects of Terrain on the Propagation of Microseismic Waves and Implantation Characteristics of Air-Delivered Sensors at Fort Huachuca, Arizona; Wet- and Dry-Season Conditions," Technical Report M-73-3, Jun 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

(3) Unconfined compressive strength (γ), kg/cm^2

(4) Compressibility parameter (ρ_p/ρ), dimensionless

(a) Soil wet density before loading (ρ), g/cm^3

(b) Soil wet density after loading (ρ_p), g/cm^3

(5) Volumetric strain (e_i) related to the elastic region of the pressure-volumetric strain curve for the material.

These parameters are determined from special uniaxial strain and triaxial compression tests performed on bulk samples obtained in the field. (See Reference 6 for a more detailed definition and description of the input parameters and how they are obtained.) Table 1 gives the values of these parameters for the terrain materials used, and Table 2 lists additional engineering data on the materials. References 4 and 5 should be consulted for additional information on the terrain materials.

2. PENETRATION AND DECELERATION PREDICTIONS

a. Inputs to the model were selected to simulate the projectile striking at an impact angle of 90 degrees (normal to the terrain surface). This impact angle was selected as the worst condition to demonstrate the upper bond of penetration. Other factors, such as mine rotational velocity, ground surface cover, ground microgeometry, etc, were not included in the theoretical study but have been identified as items that should be addressed in field data collection efforts.

b. The results of the theoretical mathematical model study (the penetration-impact velocity relations) are described herein. For the purpose of theoretical analysis, the mine was idealized as a square box having the external dimensions shown in Figure 1 and a weight of 2.31 kg. Five impact attitudes were considered: (a) 14.6- by 14.6-cm surface, (b) 14.6- by 5.8-cm surface, (c) 14.6-cm edge, (d) 5.8-cm edge, and (e) corner. These attitudes are illustrated in Figure 2. All computer calculations were made with the velocity vector normal to the surface on impact. The terrain materials selected for use ranged from soft wet clays to hard-frozen soils and low-strength rocks, as follows:

(1) Soft clay

(2) Stiff clay

(3) Sandy clay till

(4) Sandy clay fill

(5) Loose sand

(6) Dense sand

(7) Frozen sandy gravel

TABLE 1. CONSTANTS FOR TARGET MATERIALS USED IN THE THEORETICAL PENETRATION CALCULATIONS

Target Material	Modulus of Elasticity (E, kg/cm^2)	Strain-Hardening Modulus (E_t, kg/cm^2)	Unconfined Compressive Strength (γ, kg/cm^2)	Initial Wet Density ρ (g/cm^3)	Wet Density After Loading ρ_p (g/cm^3)	Compressibility Parameter (ρ_p/ρ)	Volumetric Strain (e_i)
Soft Clay	5.27×10^1	1.23	0.88	1.81	1.84	1.02	0.001
Stiff Clay	1.58×10^2	1.22	4.00	1.81	1.84	1.02	0.00
Sandy Clay Till	9.03×10^1	4.39	1.27	1.94	2.04	1.05	0.00
Sandy Clay Fill	2.95×10^2	10.7	5.86	2.06	2.13	1.03	0.00
Loose Sand	8.78×10^2	28.3	10.3	1.55	1.72	1.11	0.00
Dense Sand	3.07×10^3	22.0	48.8	1.73	1.84	1.06	0.00
Frozen Sandy Gravel	4.83×10^3	0.0	82.5	2.09	2.30	1.10	0.00
Clay Shale	1.05×10^4	0.0	70.2	2.40	2.40	1.00	0.00
Low-Strength Rock	1.05×10^5	0.0	351.4	2.06	2.32	1.13	0.00

NOTE: For an incompressible material $e_i = 0$ and $\rho_p/\rho = 1$.

TABLE 2. CHARACTERISTICS OF TARGET MATERIALS FOR THE THEORETICAL STUDY

Target Materials	USCS[a] Classification	Wet Unit Weight (g/cm^3)	Void Ratio	Saturation (Percent)	Liquid Limit	Plastic Limit	Specific Gravity	Water Content (Percent)	Remarks
Soft Clay	CH	1.80	0.880	79.1	60	23	2.68	26	- - - -
Stiff Clay	CH	1.80	0.880	30.5	60	23	2.68	10	- - - -
Sandy Clay Till	CL	1.94	0.652	87.1	41	21	2.64	22	- - - -
Sandy Clay Fill	CL	2.06	0.501	89.4	39	18	2.66	17	- - - -
Loose Sand	SP	1.55	0.720	ND[c]	NP[d]	NP	2.65	Dry	- - - -
Dense Sand	SP	1.73	0.500	ND	NP	NP	2.65	Dry	- - - -
Frozen Sandy Gravel	GW	2.09	0.334	73.3	NP	NP	2.72	9	+18 F
Clay Shale	CH	2.40	0.251	91.5	ND	ND	2.78	8.3	- - - -
Low-Strength Rock	NA[b]	2.06	NA	ND	NA	NA	ND	ND	- - - -

[a]USCS - Unified Soil Classification System

[b]NA - Not Applicable

[c]ND - No Data

[d]NP - Nonplastic

(8) Clay shale

(9) Low-strength rock.

These materials were selected to exhibit a range from very soft to very firm, and from plastic to rigid.

c. The penetration depth of the mine is defined as the distance from the surface of the ground (assumed to be horizontal) to the deepest interface of the mine and the ground after the velocity of the mine has decreased to zero. The predicted maximum penetrations into the soft materials (soft and stiff clay, sandy clay till and fill, and loose and dense sand) for the five different impact attitudes are shown in Figure 3, and into the firm materials (frozen sandy gravel, clay shale, and low-strength rock) in Figure 4. Figures 5 and 6 depict the maximum predicted decelerations experienced by the mine upon impact into the soft and firm terrain materials, respectively. The deceleration values are shown in Figures 5 and 6 as a function of terrain materials, impact velocity, and impact attitude.

d. As stated, the penetration was predicted for an impact angle that was normal to the surface of the terrain material. This angle was selected because it was assumed that impact at a normal angle would cause greater penetration than impact at lesser angles. When a mine is dropped from an aircraft, the impact angle could be considerably less than normal; therefore, normal impact could safely be considered a limiting or worst condition. Further, in actual deployment, the mine would have angular momentum (caused by its rotation) that would cause it to tumble; thus, when it struck the ground it would have a tendency to skin or roll along the surface of firm soils. If the terrain materials were soft, the mine would have a tendency to roll out of the hole that was caused by the mine's impact with the ground surface. If the mine rolls out and tumbles to a stop, it is likely to rest on its top or bottom (position A, Figure 2) and, therefore, be oriented such that it would be most effective against a target passing over it. If the mine penetrates excessively, its effectiveness could be degraded because of undersirable orientation of the explosive and because there could be considerable soil mass between the explosive and the target passing over it. The soil overburden would interface with the formation of the shaped charge jet and thereby degrade its armor penetrating capability (in the case of the AT/AV mine). Further, if soil were to adhere to the mine surface, it would not permit the explosive jet to focus as intended.

e. The roll-out of the mine under actual field conditions depends on its angular momentum and the angle of incidence of the trajectory of the instant of impact (i. e., the impact angle). Although the calculations in this theoretical study were limited to an impact angle of 90 degrees and zero rotational velocity, it was assumed that if spin were included at an impact angle of 90 degrees, the angular momentum would tend to make the mine roll out of the impact crater, provided that the initial penetration did not exceed that at which the center of gravity of the mine was even with the ground surface. This distance (called the critical depth) for the various impact attitudes shown in Figure 2 is as follows:

	Impact Attitude	Critical Depth (m)
A	14.6- by 14.6-cm surface	0.029
B	14.6- by 5.8-cm surface	0.073
C	14.6-cm edge	0.072
D	5.8-cm edge	0.103
E	Corner	0.094

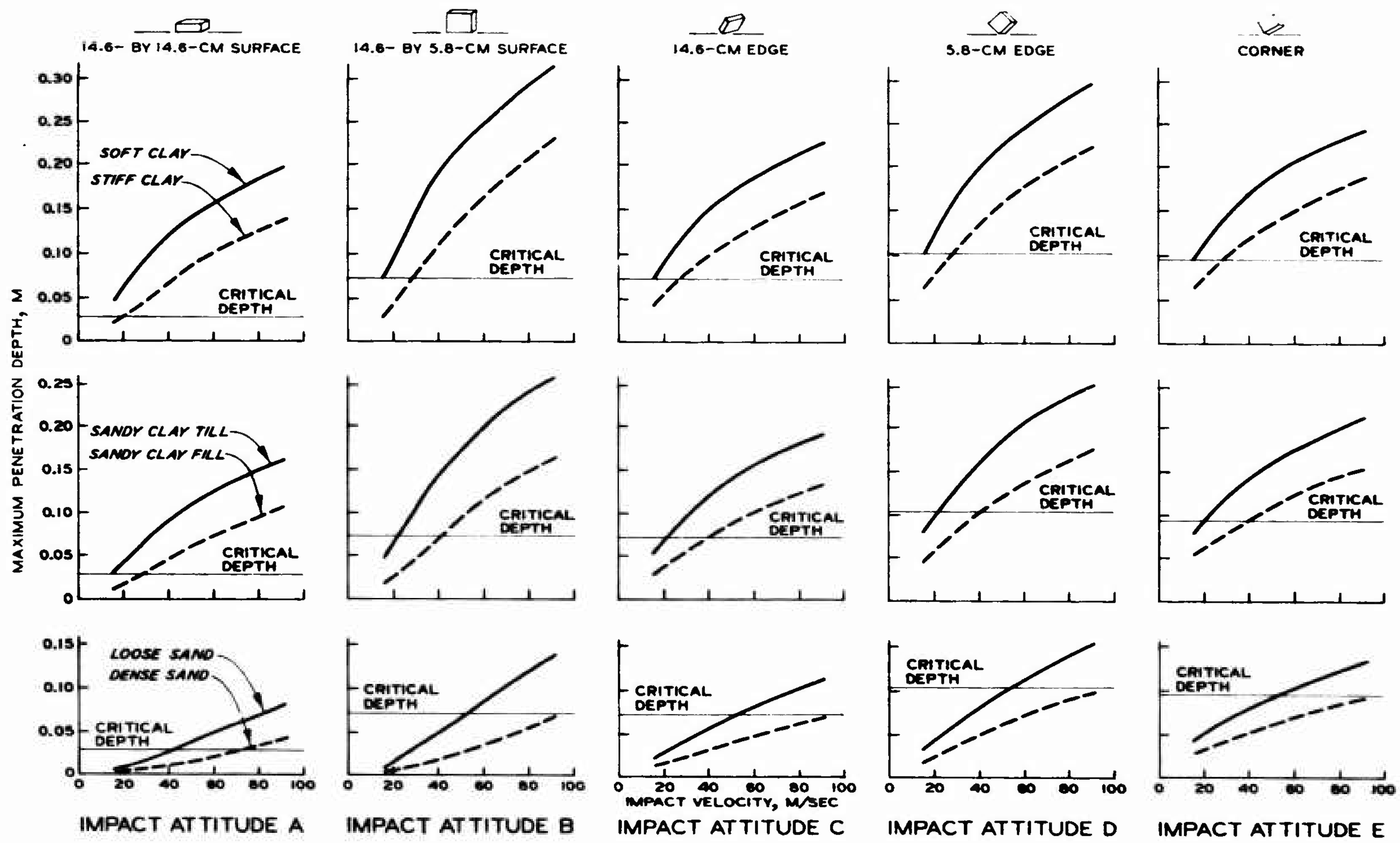


Figure 3. Theoretical Penetration Results: Penetration in Soft Target Materials

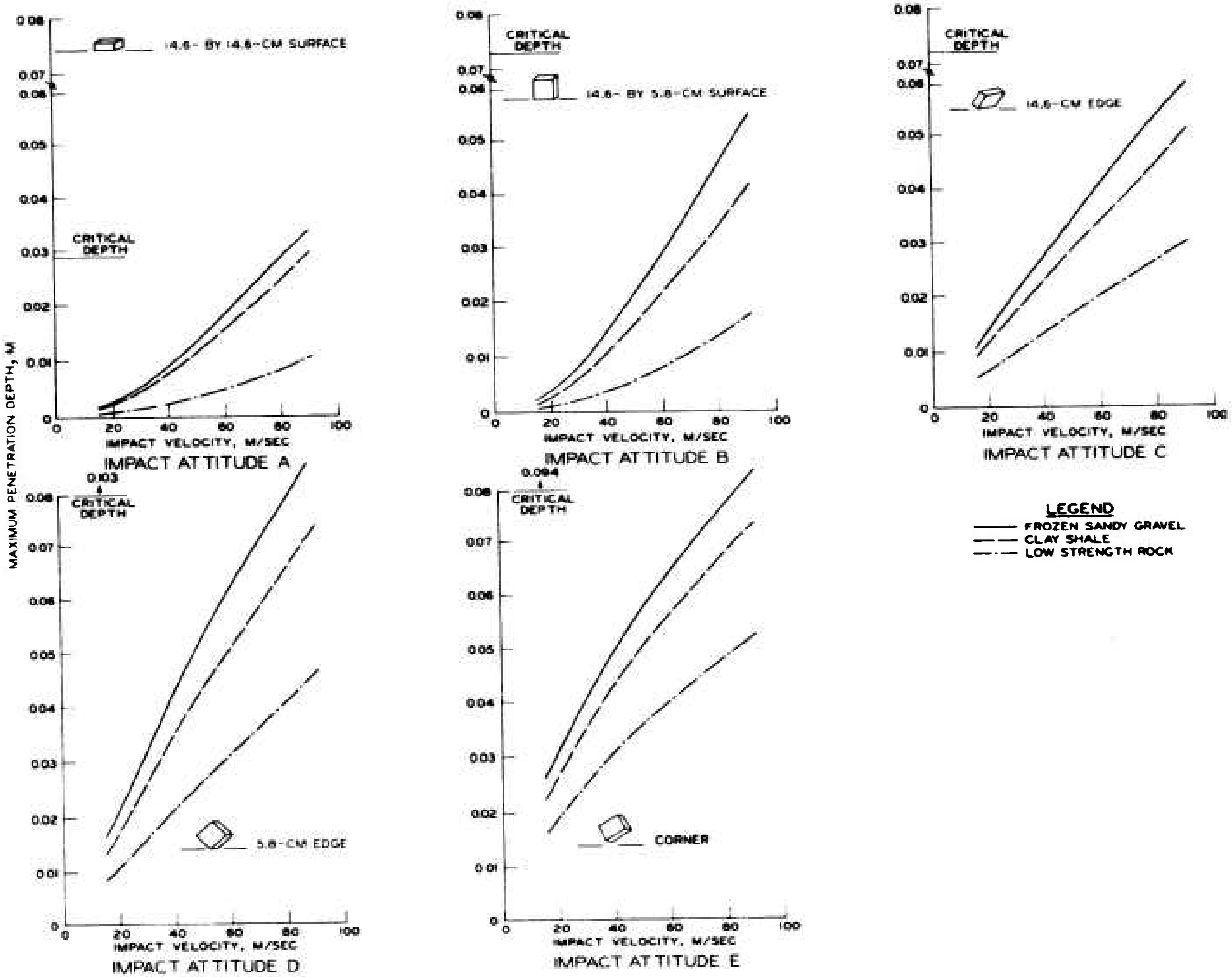


Figure 4. Theoretical Penetration Results: Penetration in Hard Target Materials

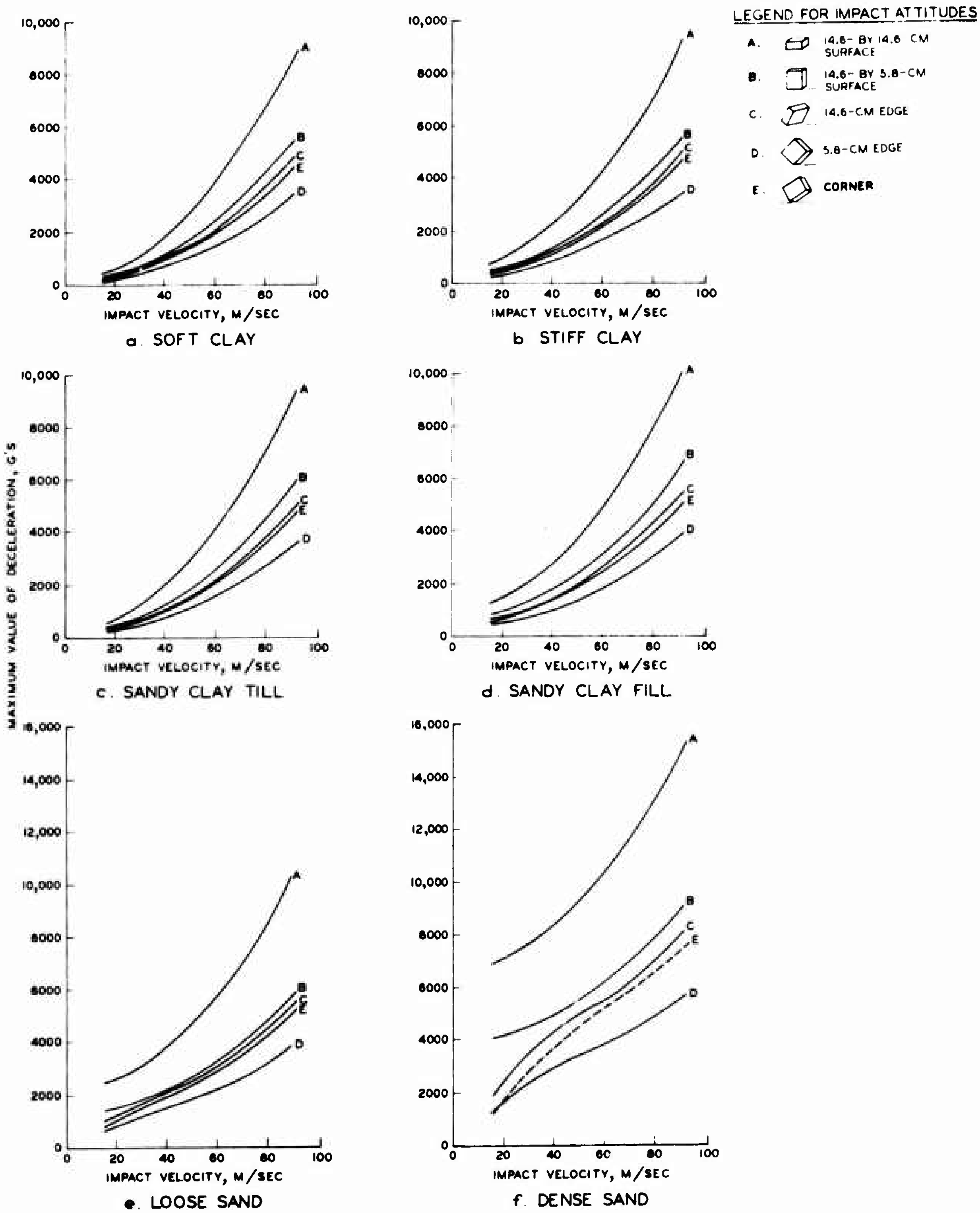


Figure 5. Theoretical Penetration Results: Deceleration in Soft Target Materials

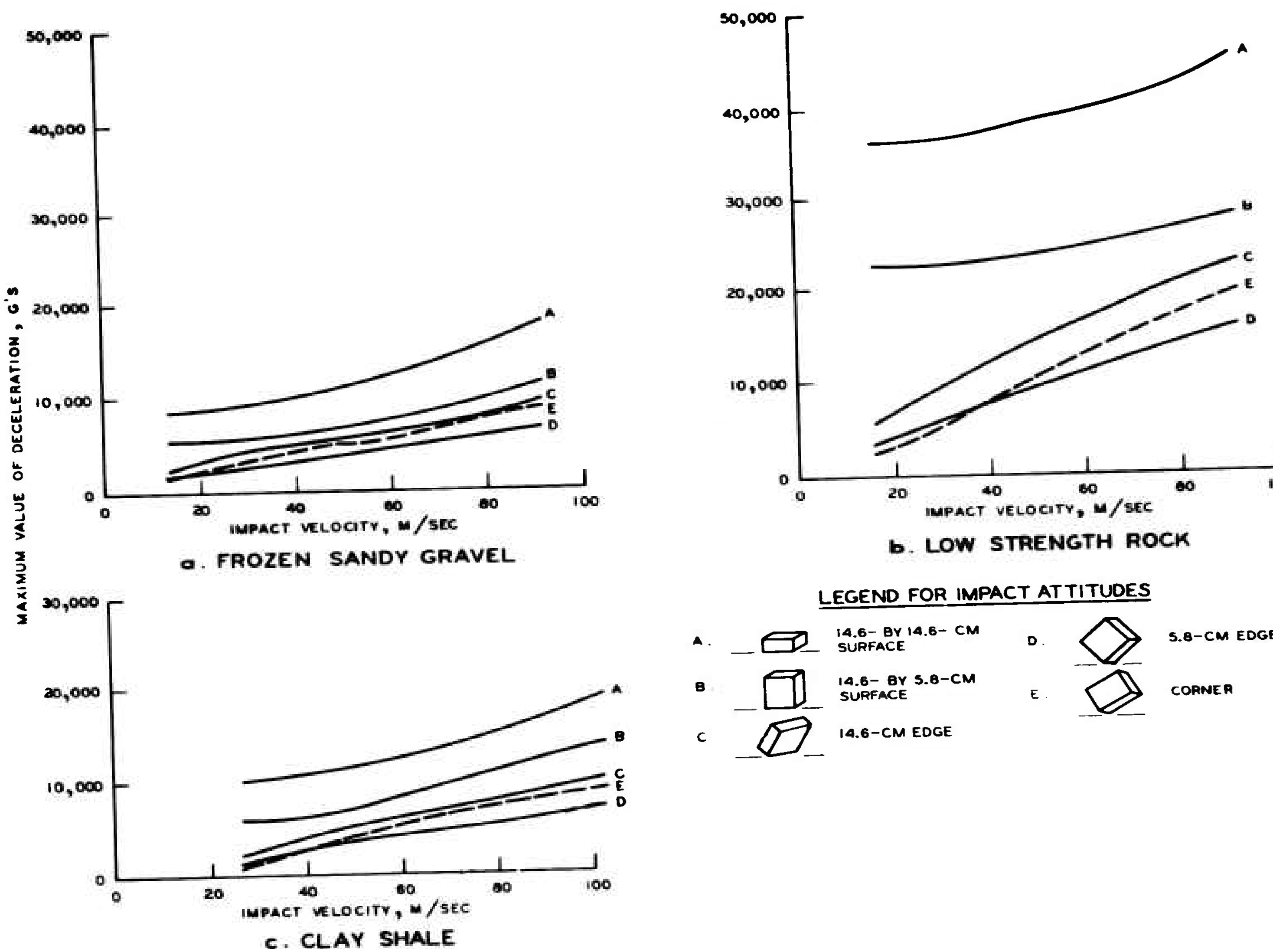


Figure 6. Theoretical Penetration Results: Deceleration in Hard Target Materials

Thus, if the mine impacts with attitude A, it is assumed that it will roll out of the impact crater only if the initial penetration is less than 2.9 cm. If the penetration is greater than the critical depth, it is assumed that the mine will remain in its impact crater. The implications of this are as follows:

(1) If the mine impacts in attitude A, it will roll out if the penetration is less than 2.9 cm. The assumption is that it will assume an at-rest attitude such that the at-rest angle (Figure 2) is near 0 degree. In this position, the mine will be effective.

(2) If the mine impacts in attitude A and penetrates to a depth of more than the critical depth but less than 5.8 cm, the mine will remain in the impact crater. However, its at-rest angle will remain at approximately 0 degree and the active face of the mine will remain above the surface and therefore free of debris. In this situation, the mine will be effective.

(3) If the mine impacts in attitude A and the initial penetration is greater than 5.8 cm, the mine will remain in its impact crater but the active face may eventually be covered with debris. In this situation, the mine will be ineffective, even though the at-rest angle is approximately 0 degree.

(4) If the mine impacts in attitudes B, C, and D and initial penetration is less than the respective critical depths, the mine will roll out of the impact crater and eventually come to rest with a 14.6- by 14.6-cm face on the ground. The at-rest angle will be nearly 0 degree, and in this situation, the mine will be effective.

(5) If the mine impacts in attitudes B, C, and D and penetrates to a greater depth than the respective critical depths, the mine will remain in its impact crater, and will be ineffective either because the at-rest attitude will exceed 30 degrees, or because the active face will eventually be covered with debris, or both.

The critical depth is shown on each of the depth of penetration-impact velocity curves (Figures 3 and 4) as a reference for judging penetration.

f. In Figure 1 the maximum depth of penetration for the soft terrain materials ranges from less than 0.01 meter to more than 0.3 meter over the impact velocities studies. Penetration was excessive at impact velocities of less than 92 meters per second for most of the softer soils, as summarized below.

Terrain Materials	Lowest Velocity (Meters per Second) at which Penetration was Excessive				
	Impact Attitude				
	Surface		Edge		Corner
	A (14.6-by 14.6-cm)	B (14.6-by 5.8-cm)	C (14.6 cm)	D (5.8 cm)	E
Soft Clay	19	15	15	16	15
Stiff Clay	36	28	27	29	27
Sandy Clay Till	26	22	22	22	20
Sandy Clay Fill	49	41	40	41	40
Loose Sand	69	53	53	55	52

Penetration was not excessive for dense sand over the velocity of 15 to 92 meters per second. The tabulation above shows that excessive penetration depths for each soil were found to occur at approximately the same impact velocity for four of the five impact attitudes, i.e., B, C, D, and E. Excessive penetration for impact attitude A was not reached until the impact velocity was approximately 25 percent greater than for the other four impact attitudes. Thus, it would appear that if the impact attitude could be controlled, attitude A would be selected, because a wider range of impact velocities could be tolerated in deployment.

g. Another way of viewing excessive penetration in the soft soils is by looking at the ratio of depth of penetration to the critical depth (i. e., depth of penetration normalized by the critical depth) at an intermediate value of impact velocity (e. g., 46 meters per second). Any value greater than two for impact attitude A or greater than one for impact attitudes B, C, D, and E in the tabulation below indicates excessive penetration.

Terrain Materials	Depth of Penetration at 46 Meters per Second Normalized by Critical Depth				
	Impact Attitude				
	Surface		Edge		Corner
	A (14.6-by 14.6-cm)	B (14.6-by 5.8-cm)	C (14.6 cm)	D (5.8 cm)	E
Soft Clay	4.53	2.89	2.23	2.07	1.93
Stiff Clay	2.70	1.75	1.50	1.42	1.39
Sandy Clay Till	3.50	2.23	1.81	1.69	1.62
Sandy Clay Fill	1.86	1.16	1.13	1.08	1.11
Loose Sand	1.16	0.80	0.87	0.88	0.92
Dense Sand	0.48	0.32	0.50	0.54	0.63

h. All the normalized values of penetration depth for loose and dense sand are less than one for impact conditions B, C, D, and E. For these conditions excessive penetration is found in the clay and sandy clay soil. Finally, the tabulation above shows that for impact condition A, successful emplacement can be expected in the loose and dense sand and the sandy clay fill. Note that if the mine stays in the impact hole for the impact attitude other than the 14.6- by 14.6-cm surface, it is not oriented for optimum functioning. Even if a charge is used to clear away the overburden, the effectiveness of the mine will be degraded if it is aimed away from the target. This will still be the case if the mine impacts at angles other than normal to the surface (i. e., the velocity vector is at an angle other than perpendicular to the surface).

i. As illustrated in Figure 4, penetration will not be excessive at any velocity between 15 and 92 meters per second in the firm terrain materials (i. e., frozen sandy gravel, clay shale, and low-strength rock).

j. The maximum penetration for the Gator mine at any given impact velocity or impact attitude is in the soft clay (Figure 3). The penetration depths are generally greater in sandy clay than in sand, although both materials show penetration depths less than those in clay. The range of penetration values for sandy clay is indicated by the curves for sandy clay till and sandy clay fill; for sand the range is indicated by the curves for loose and dense sand. As stated previously, the penetration depth is least in frozen sandy gravel, clay shale, and low-strength rock (Figure 4).

k. In interpreting the curves shown in Figures 3 and 4, it should be emphasized that because of the highly variable nature of soils, values of penetration depth generally will not fall exactly on any one penetration curve. Typically, the penetration depths will indicate a range of values which, in the case of clay, could usually be assumed to be bounded by the curves for soft and stiff clay. Similar statements could be made for the other terrain materials.

l. The penetration-impact velocity curves correspond to idealized homogeneous materials. (Factors such as surface roughness, vegetation, and increase of strength of soil with depths were not included in the penetration calculations.) In general, an increase in soil strength with depth will tend to reduce penetration. Surface roughness may cause the mine to tumble upon impact, and vegetation may damp out projectile motion and penetration to some degree. Under certain conditions it must be assumed that the presence of surface roughness and vegetation will result in increased penetration (i. e., vegetation may retain moisture that would result in a weaker soil structure).

m. Even though in situ soils usually have rough surfaces and in many cases are covered by surface vegetation, it is assumed that the penetration-impact velocity curves in Figures 3 and 4 provide reasonable upper limits of penetration for the real terrain materials that were represented in the simulation. Because many of the terrain materials studied permit excessive penetration under the conditions (worst case) studied, it must be concluded that the Gator mine implantation performance has not been sufficiently defined to predict that the present design will implant adequately in all real-world terrains. However, because the theoretical study represented worst-case conditions (i. e., impact normal to the surface) which are not representative of typical or average conditions, further theoretical and empirical study was deemed necessary to determine implantation performance where the mine impacts at angles other than at 90 degrees to the surface. Hence, the test program described in Section III.

n. The computed maximum values of decleration versus impact velocity for the five impact attitudes for the soft and firm terrain materials are shown in Figures 5 and 6, respectively. The deceleration values are for homogeneous terrain materials. The maximum value of deceleration occurs at impact in those cases where mine contact cross-sectional areas remain constant (impact attitudes A and B) as velocity decreases to zero. The maximum value of deceleration will occur at some time after impact for configurations of the mine in which its contact cross-sectional area changes as it penetrates the target material (impact attitudes C, D, and E). The calculated results presented in Figures 5 and 6 are for rigid-body deceleration only. (Stress levels produced inside the mine may be much higher than those calculated from rigid-body deceleration because of reflection of stress waves at boundaries of a nonrigid body.)

o. Deceleration values are tabulated below for an impact velocity of 46 meters per second in the various target materials.

Maximum Deceleration (g) at 46 Meters per Second

	Impact Attitude				
	Surface		Edge		Corner
Terrain Materials	A (14.6-by 14.6-cm)	B (14.6-by 5.8-cm)	C (14.6 cm)	D (5.8 cm)	E
Soft Clay	2,339	1,454	1,265	892	1,171
Stiff Clay	2,731	1,674	1,471	1,025	1,364
Sandy Clay Till	2,566	1,597	1,364	961	1,259
Sandy Clay Fill	3,380	2,152	1,796	1,268	1,651
Loose Sand	2,454	4,292	2,299	1,613	2,171
Dense Sand	8,819	5,277	4,661	3,202	4,196
Frozen Sandy Gravel	10,794	6,678	5,497	3,749	4,788
Clay Shale	12,460	8,894	6,641	4,586	5,590
Low-Strength Rock	38,166	23,661	13,389	8,607	9,239

Figures 5 and 6 and the tabulation above show that the highest deceleration values were obtained for impact attitude A in the firmer materials, especially the low-strength rock. As expected, the curves show that the deceleration values increase nonlineraly with impact velocity. As the deceleration values increase the depth of penetration increases.

SECTION III

MEASURED PENETRATION CHARACTERISTICS

The theoretical study revealed that further investigation was needed to determine emplacement performance of the Gator mine. In this context, it is important to note that the actual motion of the mine consists of two independent modes: the movement along its trajectory from aircraft (or dispenser) to the ground, and the spin of the mine, induced by aerodynamic forces on the case. While the spin is variable and dependent upon velocity along the trajectory, the rate is such that the mine rotates about one full turn during the time it advances about 1.2 meters along its trajectory. The theoretical models that were available were not capable of simulating such complex motions and, thus, could not be used to predict mine performance in completely operational modes. Specifically, it was assumed that the rotation of the mine, coupled with small impact angles, would decrease penetration such that little or no soil would cover the mine in the final (at-rest) position.

Since the theoretical model could not be used, the actual performance of the mine had to be studied empirically. An air gun was used to fire an inert Gator mine into three soil conditions, ranging from quite soft to very firm, to simulate air delivery of the mine (Figures 7 and 8). Ninety-three firing events took place. This section describes the gun and firing procedures, test sites, test procedures and data collected, and the analysis of the data derived.

1. DESCRIPTION OF AIR GUN AND FIRING PROCEDURES

a. Air Gun

(1) The Gator air gun is a new prototype built by Honeywell Corporation and is composed of a barrel, the air pressure system, the firing mechanism, and the hydraulically controlled aiming mechanism. The entire gun and ancillary equipment are carried on an 8-ton, 4-wheel trailer. The gun uses an air charge to propel the mine (enclosed in a sabot) and, by varying the air pressure, the range of impact velocities can be varied from 40 to 80 meters per second. The firing angle of the gun can be varied from 20 to 90 degrees (measured from a horizontal reference) by tilting the boom upon which the barrel and firing system are mounted. In addition, the air gun design includes a mechanism that is used to rotate or spin the mine. The various components of the gun are described in the following paragraphs.

(2) Barrel. The barrel was designed especially for firing the Gator mine. It is rectangular and is made of an aluminum alloy (6061-T6) with inside dimensions 21.6- by 23.5- by 121.9-cm long. The barrel is attached to a trailer by a tubular boom 4.34 meters long. When the boom is raised to the 90-degree position (i. e., the barrel is 90 degrees with the horizontal), the bottom of the barrel is 4.73 meters above the ground level. A breech latch assembly is located in the end of the barrel to latch the tank (the air pressure system) to the barrel prior to firing. There are two holes in the breech of the barrel; one hole is used to anchor a ribbon holder and the other is used to hold the sabot assembly in place.

Figure 7. Air Gun in Position for Firing a Mine into the Ground on an Incidence Angle of 90 Degrees

Figure 8. Air Gun in Process of Firing a Mine into the Ground at an Impact Angle of 50 Degrees

(3) Air Pressure System. The air pressure system consists of a 0.042-m^3 steel tank in which nitrogen gas is stored under pressure to fire the gun. The tank is filled prior to each shot from C-size high-pressure bottles controlled by a regulator. Two gages are used to read the pressure during the pressurizing procedures, and a dump valve is provided in case of emergencies.

(4) Firing Mechanism. The gun is fired by releasing a valve separating the tank and the barrel. The valve mechanism, a 12.2-cm aluminum flapper disc, is attached to the tank on the barrel side with an O-ring and is held closed by loading a torsion spring until it catches. To activate the valve a current controlled by a remote switch is passed through a 110-volt solenoid, which releases the catch. The preloaded torsion spring on the valve is then released and the gas expands into the barrel, forcing out the sabot holding the mine.

(5) Aiming Mechanism. The gun is aimed by using a hydraulic system to raise and lower the boom. The hydraulic system is controlled by a valve on a control panel and is powered by a 110-volt pump (3/4 horsepower) or by a backup manual pump. The boom can be stopped at any angle from the horizontal on either the way up or the way down by means of a double pilot check valve which hydraulically locks the boom when the control valve is in the neutral position.

(6) Spin Mechanism. The spin mechanism (Figure 9) consists of two sabot halves, a spin-up ribbon, and a ribbon holder. The two sabot halves completely enclose the mine and seal the barrel of the gun so that the air can force the mine from the barrel. The sabot halves are made from water-blown urethane foam of 0.13- to 0.16-g/cm^3 density. The spin-up (attached to a ribbon holder) is wrapped around the two sabot halves containing a mine and secured with fiberglass tape. When the unit is fired from the gun, the ribbon holder (and ribbon) remain in the barrel and give the sabot-mine combination a high-speed spinning motion.

(7) Splitter Assembly. To insure separation of the sabot halves enclosing the mine during the firing process, a splitter assembly was designed, fabricated, and fastened on two sides of the barrel. The splitter assembly consists of two extension plates (each with a center ridge) fastened on the end of the barrel. The ridge serves to separate the sabot halves as the sabot rolls out the end of the barrel and travels over the extension plates. The extension plates are 22.86 cm long. The ridge is 0.635 cm wide and 15.24 cm long. At the end of the barrel the ridge is 0.317 cm high; at 15.24 cm from the barrel it is 0.635 cm high. The ridge is butted into a wedge at 15.24 cm from the barrel. The wedge tapers from a width of 0.635 cm at the butt to 1.27 cm at its extreme end. Also, it tapers from a height of 0.635 cm at the end of the ridge to 0.952 cm at the extreme end of the assembly. Both the ridge and the wedge are replaceable by means of bolts through the extension plates.

b. Firing Procedures

(1) Procedures were developed to ensure that all firing events were performed in an identical fashion so that variations in the data would be caused by the penetration characteristics of the terrain materials alone. To load the sabot and mine into the air gun,

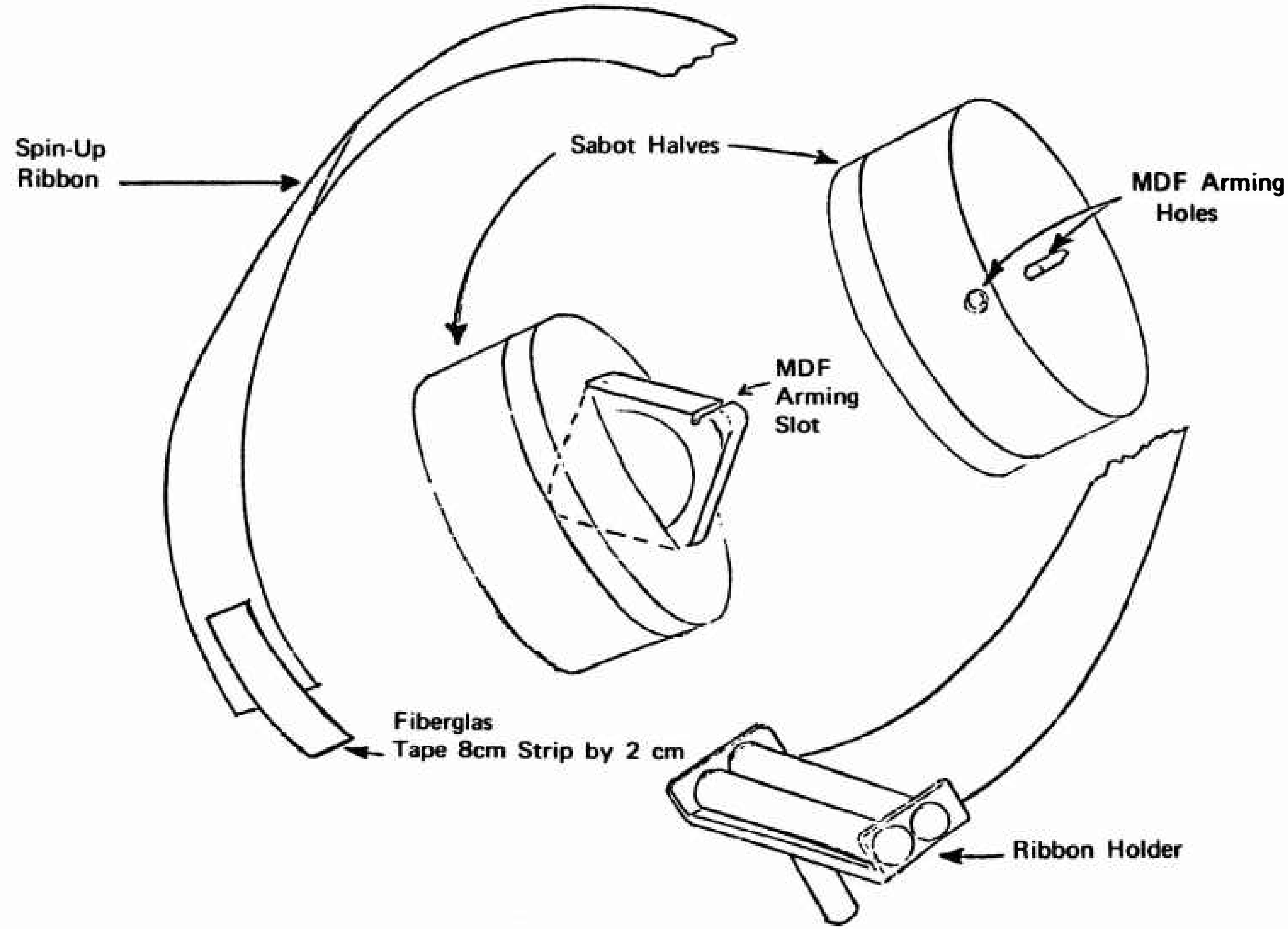


Figure 9. Method of Attaching Ribbon to Sabot and Ribbon Holder

the boom must be fully lowered and the breech opened. The sabot halves are then placed together over a mine, and the end of the spin-up ribbon is secured to the sabot by a piece of fiberglass tape. The ribbon is wound around the sabot halves and the free end is secured to the ribbon holder. The complete unit (mine, sabot, ribbon, and ribbon holder) is then inserted into the breech. The sabot is pushed in while the ribbon holder is kept to the rear of the barrel so that it can be dropped into the hole provided at the rear of the barrel. (A small bolt was located on the breech latch side of the barrel to adjust the fit if the sabot is loose and rolls backward.) The breech is then closed by swinging the tank up against the back of the barrel until it catches; it is secured by tightening the locking bolt.

(2) The last step before raising the gun to firing position is cocking the flapper valve. The gun can then be raised into firing position with the hydraulically controlled aiming system. A level and angle finder placed against the boom near the pivot point are used to position the barrel to the desired angle of incidence. After attaining the correct position, the regulator on the gas cylinder is opened until the pressure gage indicates that the gas in the firing tank has stabilized at the required shot pressure. After personnel are cleared from the area, a shot is completed by pressing the firing switch and turning off the gas regulator to stop loss of gas through the barrel after firing.

2. GENERAL DESCRIPTION OF THE TEST SITES

The air gun was used to fire the Gator mine at two test sites, one of lean clay and one of fat clay, classified CL and CH, respectively, according to the Unified Soil Classification System. Tests were conducted in both dry and wet lean clay and in wet fat clay, thereby providing three soil conditions for testing.

a. Lean Clay (Loess) Site

The lean clay site was at latitude 90°51'40" North and longitude 32°18'35" West (on the grounds of the WES). Its location made it ideally suited for use as an area to calibrate the air gun. The soil at the site is typical of lean clay soils derived from loess parent material. Since loess soils occur commonly throughout the world, test results obtained at the site should not be anomalous to results obtained in similar soils. Characteristically, the soils are well drained and occur on strongly sloping to steep uplands The landscape is often highly dissected, and the hillsides are too steep for modern cultivation. Vegetation on the soils in the vicinity of the WES often consists of hardwoods with an understory of dogwood, holly, hawthorn, low shrubs, and vines. The soil has an open structure, but it can exhibit good strength when dry. When wet, the soil can be much weaker than when dry. When the calibration shots were conducted, it was assumed that the site exhibited an intermediate soil condition, i. e., much stronger than the fat clay site, but sill much weaker than many soils. Tests were also conducted when the site was artifically wetted to represent soil conditions between those used for the calibration tests and those at the fat clay site. The wet condition was obtained by tilling the soil (by rotor), impounding water for 72 hours, and then draining the water.

b. Fat Clay (Buckshot) Site

The fat clay site was located at longitude 91°04'25" North and latitude 32°33'30" West (just north of Eagle Lake, Mississippi). The soil strength at the site was just sufficient to permit passage of heavy tracked vehicles. The site was selected to present a limiting case where the mine would have to be deployed, i. e., a softer soil would effectively deny vehicle access to such areas because of poor trafficability and thus eliminate the need for an AV mine (even though the mine would penetrate excessively). Buckshot clay is typical of deep clayey soils formed from slack-water sediments. These fine-grained alluvial soils normally occur in areas that are periodically flooded by a major river such as the Mississippi. The soils are quite soft and sticky when wet and are characteristically cohesive and firm when dry. They are often cultivated (soy beans, cotton, corn, etc), but in their natural state, they can support a wide variety of tree species, such as red maple, sweet gum, and oaks of various kinds. Tests were conducted at this site when the soil was naturally wet.

3. TEST PROCEDURES AND DATA COLLECTED

The test program had two interrelated parts: (a) calibration of the air gun and (b) generation of data and characteristics of the mine performance and the test sites.

a. Calibration of the Air Gun

The air gun was calibrated by measuring the spin rate, impact angle, and velocity of the mine and correlating these parameters with the air pressure used to propel the sabot-mine assembly. The spin rate and impact velocity were recorded with high-speed photography. The values of these parameters were determined by study of the location of the mine in sequential frames of the photography.

b. Characterization of Mine Performance

After calibration, the gun was used to generate data to study the performance of the mine. Mine performance was characterized in two ways, i. e., initial impact and post-impact conditions. If the mine penetrated the ground and remained there, the penetration depth (and the thickness of material covering the mine surface) and the inclination from horizontal were measured. If the mine impacted the ground and bounced and rolled, the final inclination (from horizontal) of the mine was measured. Also, the initial penetration (before bounce) was determined by measuring the indentation caused by the mine impact. Further, the amount of overburden on the mine surface after bounce was recorded. Measurement of mine penetration and impact condition is illustrated in Figure 10.

c. Characterization of Test Sites

The implantation performance of a mine is closely related to site conditions; therefore, care was taken in characterizing each test site. In addition to the general description of each site, the following parameters were measured and documented during the test program:

(1) Soil strength in terms of trafficability cone index

(2) Soil strength in terms of the dynamic cone index[1]

(3) Vegetation or gound cover

Footnote

[1]The dynamic cone penetrometer was develped by Sandia Laboratories to derive a quantitative indication of the penetration resistance of soils.

Figure 10. Measurement of Gator Mine Penetration and Impact Condition

(4) Soil moisture content

(5) Atterberg limits

(6) Soil density.

Photographs also were taken where appropriate.

Soil strength can vary significantly even in a small test area such as those used in the test program. (Each test area was approximately 50 by 50 meters.) For this reason, three repetitions of each soil strength measurement (i. e., trafficability and dynamic cone indexes) were made within 1 meter of where a mine impacted. Trafficability cone index readings were taken at depth increments of 2.5 cm, and the readings from the three repetitions were averaged over a depth equal to the penetration of depth of the mine. The dynamic cone index values are the numbers of blows required to drive the cone 15 cm into the soil. These values were averaged for the three repetitions at each impact point. Vegetation or ground cover was described at the point of each impact, and one or more photographs of the impact point and final resting place of the mine were taken. To determine soil moisture content, Atterberg limits, and soil density, three to seven soil samples were obtained from the 0- to 15-cm layer within a 10-meter-diameter area that encompassed the area where the mine impacted.

The data discussed above were collected for each of the 93 firing events making up the test program. The strength and vegetation data are tabulated in Table 3. The ranges and average values of the parameters (except vegetation) for the two test sites are discussed below. Vegetation cover was present in only a small number of tests (Table 3).

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm^2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
Dry Lean Clay, Dry Density = 1.75 g/cm^3, Moisture Content = 15 Percent														
1	550	24	None	53.1	90	42.04	1059	6.0	A	20	6.0	22	0.1	Calibration Test
2	650	23	None	53.1	90	41.56	756	7.0	E	25	7.0	14	0	Calibration Test
3	550	26	None	53.1	90	39.33	1765	5.0	A	0	5.0	29	0	Calibration Test
4	700	35	Partial Grass Cover	53.1	90	41.56	1268	4.0	A	0	0	4	0	Calibration Test
5	700	34	Partial Grass Cover	53.1	90	42.53	891	4.0	A	0	0	0	0	Calibration Test
6	650	28	None	63.5	90	60.96	1091	12.0	D	75	12.0	34	0	Calibration Test
7	725	26	None	63.5	90	58.76	1364	5.0	A	0	0	0	0	Calibration Test
8	625	32	None	63.5	90	54.18	2791	6.0	A	10	6.0	0	0	Calibration Test
9	750+	44	Partial Grass Cover	63.5	90	51.88	1000	10.0	D	70	0	0	0	Calibration Test
10	750+	40	Partial Grass Cover	63.5	90	60.21	1000	11.0	C	50	11.0	0	0	Calibration Test
11	750+	41	Partial Grass Cover	100.0	90	85.56	1212	7.5	A	21	7.5	10	0	Calibration Test
12	750+	41	Partial Grass Cover	58.7	90	46.89	476	5.0	A	0	5.0	14	0	Calibration Test

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONTINUED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm^2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
13	750+	24	None	93.2	90	72.79	1967	11.0	C	47	11.0	86	0	Calibration Test
14	450	18	None	93.2	90	70.68	659	7.5	A	6	7.5	30	0	Calibration Test
15	500	22	None	93.2	90	73.88	909	8.0	A	19	8.0	25	0	Calibration Test
16	500	25	None	96.6	90	75.03	594	7.5	A	20	7.5	24	0	Calibration Test
17	700	22	None	96.6	90	63.33	706	6.5	A	0	6.5	6	0	Calibration Test
18	600	20	None	89.7	90	71.72	577	13.0	E	52	13.0	38	0.1	Calibration Test
19	600	19	None	89.7	90	72.79	619	7.0	A	0	7.0	10	0	Calibration Test
20	675	23	None	65.6	90	60.21	484	8.0	A	20	8.0	10	0.1	Calibration Test
21	675	24	None	65.6	90	58.76	373	9.0	E	35	9.0	20	0.1	Calibration Test
22	750+	33	None	65.6	90	60.21	1053	12.0	B	75	12.0	45	0	Calibration Test
23	750+	45	Partial Grass Cover	58.7	90	44.07	652	9.5	E	60	. . .	0	0	Calibration Test
24	750+	44	Partial Grass Cover	58.7	90	46.89	576	10.5	E	60	. . .	32	0	Calibration Test
25	750+	50	None	58.7	90	45.15	308	6.0	A	10	. . .	90	0	Calibration Test

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONTINUED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
Wet Fat Clay, Dry Density = 1.79 g/cm^3, Moisture Content = 31 Percent														
26	80	1	None	58.7	90	48.8	None Taken	30.5	A	1	30.5	0	0	No overburden on mine but several pieces of clay soil fell in on mine.
27	110	3	None	65.6	90	55.0	None Taken	22.9	A	3	22.9	0	0	No overburden on mine but several pieces of clay fell in on mine.
28	100	3	None	96.6	90	77.0	None Taken	30.5	E	60	30.5	71	0	Impacted on a root.
29	65	4	None	58.7	90	48.8	None Taken	35.6	D	90	35.6	70	0	
30	115	3	None	65.6	90	55.0	None Taken	27.9	E	45	27.9	60	0	
31	100	4	None	96.6	90	77.0	None Taken	55.9	D	90	55.9	55	0	
32	100	3	None	58.7	90	48.8	None Taken	21.6	C	45	21.6	60	0	Impacted on a root.
Wet Fat Clay, Dry Density = 1.74 g/cm^3, Moisture Content = 33 Percent														
33	90	3	None	65.6	90	55.0	None Taken	25.4	A	0	25.4	25	0	Pieces of clay soil fell in on mine.
34	70	4	None	96.6	90	77.0	None Taken	33.0	A	0	33.0	65	0	Pieces of clay soil fell in on mine.
35	85	4	None	58.7	90	48.8	None Taken	40.6	B	90	40.6	90	0	Pieces of clay soil fell in on mine.
36	100	4	None	65.6	90	55.0	None Taken	26.7	C	45	26.7	60	0	Wrap-up ribbon broke.

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONTINUED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm^2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
37	100	4	None	96.6	90	77.0	None Taken	26.7	A	0	26.7	5	0	Wrap-up ribbon broke. Pieces of clay soil fell in on mine.
38	95	4	None	58.7	90	48.8	None Taken	19.0	A	0	19.0	5	0	
39	110	4	None	65.6	90	55.0	None Taken	27.9	C	60	27.9	75	0	Wrap-up ribbon broke.
40	70	6	None	96.6	90	77.0	None Taken	58.4	A	0	58.4	85	0	
Wet Fat Clay, Dry Density = 1.73 g/cm^3, Moisture Content = 32 Percent														
41	95	4	None	65.6	50	55.0	None Taken	27.9	C	45	27.9	35	30.5	Made a 45-degree angle hole; all buried but top edge of mine.
42	110	3	None	65.6	50	55.0	None Taken	16.5	A	0	16.5	10	0	Slid on surface 38 cm.
43	110	4	None	65.6	50	55.0	None Taken	16.5	A	13	16.5	21	0	Slid on surface 30 cm. Half of firing face covered by clay 5 cm thick.
44	100	4	None	65.6	50	55.0	None Taken	20.3	A	0	20.3	35	00	Half firing face covered. Slid 10 cm.
45	100	4	None	65.6	50	55.0	None Taken	30.5	C	60	30.5	85	0	
Wet Fat Clay, Dry Density = 1.70 g/cm^3, Moisture Content = 31 Percent														
46	100	4	None	65.6	20	55.0	None Taken	15.2	C	30	0	0	0	Flipped once, landed clean side up.

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONTINUED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm^2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
47	95	3	None	65.6	20	55.0	None Taken	13.9	C	25	0	0	0	Bounced off to right at 45 degrees.
48	90	4	None	65.6	20	55.0	None Taken	17.8	C	45	17.8	35	0	Slid 40.5 cm on surface.
49	75	4	None	65.6	20	55.0	None Taken	10.2	C	60	0	0	0	Bounced 3 times.
50	100	4	None	65.6	20	55.0	None Taken	14.0	B	75	0	0	0	Bounced once.
Wet Fat Clay, Dry Density = 1.76 g/cm^3, Moisture Content = 28 Percent														
51	80	7	None	58.7	90	48.8	None Taken	34.3	B	90	34.3	71	0	Wrap-up ribbon came out.
52	110	7	None	65.6	90	55.0	None Taken	20.3	B	90	20.3	79	0	Mine halves were loose.
53	95	7	None	96.6	90	77.0	None Taken	25.4	A	0	25.4	35	0	Pieces of clay soil fell in on mine.
Dry Lean Clay, Dry Density = 1.79 g/cm^3, Moisture Content = 15 Percent														
54	560	24	None	65.6	50	55.0	None Taken	9.0	C	34	0	0	0	Wrap-up ribbon pulled out.
55	750	30	None	65.6	50	55.0	None Taken	10.0	C	46	0	0	0	
56	425	21	None	65.6	50	55.0	None Taken	3.5	A	0	0	0	0	
57	350	31	None	65.6	50	55.0	None Taken	5.0	A	0	0	0	0.2	
58	400	31	None	65.6	20	55.0	None Taken	4.0	A	0	0	0	0	

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONTINUED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm²)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
59	400	30	None	65.6	20	55.0	None Taken	4.0	A	0	0	0	0	
60	450	26	None	58.7	90	48.8	None Taken	4.0	A	0	4.0	7	0	
61	600	30	None	65.6	90	55.0	None Taken	5.5	A	0	5.5	25	0	
62	700	26	None	96.6	90	77.0	None Taken	6.0	A	10	6.0	24	0	
63	500	24	None	96.6	90	77.0	None Taken	9.5	A	16	9.5	10	0.05	
64	500	24	None	96.6	90	77.0	None Taken	14.5	E	58	14.5	64	0	Mine face half covered.
65	500	20	None	58.7	90	48.8	None Taken	7.0	A	15	7.0	2	0	
66	525	21	None	65.6	90	55.0	None Taken	5.5	A	6	5.5	0	0	
67	300	21	None	65.6	20	55.0	None Taken	4.0	A	0	0	0	0	
68	400	21	None	65.6	20	55.0	None Taken	4.0	A	0	0	90	0	Started to roll on sides ended up standing on side.
Wet Lean Clay, Dry Density = 1.84 g/cm³, Moisture Content = 18 Percent														
69	90	5	None	58.7	90	48.8	None Taken	29.0	B	90	29.0	85	0	Mine totally covered with loose soil.
70	95	5	None	65.6	90	55.0	None Taken	24.0	B	75	24.0	65	0	One-half of mine face buried.

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONTINUED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm^2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
71	150	4	None	96.6	90	77.0	None Taken	32.0	C	50	32.0	45	0	Wrap-up ribbon broke, one-half of mine face buried.
72	210	6	None	58.7	90	48.8	None Taken	23.0	E	45	23.0	45	0	One-half of mine face buried.
73	120	6	None	65.6	90	55.0	None Taken	20.5	C	50	20.5	53	0	One-half of mine face buried.
74	240	6	None	96.6	90	77.0	None Taken	28.0	E	30	28.0	38	0	Mine totally covered with loose soil.
75	- -	4	None	58.7	90	48.8	None Taken	18.0	E	40	18.0	43	0	Mine halves were loose.
76	- -	4	None	65.6	90	55.0	None Taken	21.0	E	40	21.0	40	0	
77	260	5	None	96.6	90	77.0	None Taken	28.0	C	56	28.0	60	0	Mine totally covered with loose soil.
78	150	4	None	65.6	50	55.0	None Taken	18.0	A	0	18.0	15	0.5	Mine under soil at an angle.
79	200	3	None	65.6	50	55.0	None Taken	19.0	A	0	- - -	90	0	Sabot halves hit boom pivot.
80	300	4	None	65.6	50	55.0	None Taken	22.0	A	10	22.0	90	0	Mine bounced straight up and landed in impact hold.
81	58	5	None	65.6	20		None Taken	4.5	A	10	- - -	0	0	Sabot halves hit on pivot of boom.
82	90	3	None	65.6	20	55.0	None Taken	9.0	A	0	- - -	0	0	

TABLE 3. RESULTS OF FIELD PENETRATION TESTS AT WES USING GATOR AIR GUN (CONCLUDED)

Test No.	Cone Index	Dynamic Cone Index	Vegetation Cover	Firing Tank Pressure (N/cm^2)	Firing Angle (deg)	Mine Impact Velocity[a] (m/sec)	Mine Spin Rate[a] (rpm)	Initial Mine Penetration Depth (cm)	Mine[b] Impact Attitude	Mine Impact Orientation (deg)	Final Mine Penetration Depth (cm)	Final Mine Orientation (deg)	Thickness of Material Covering Mine Surface After Shot (cm)	Remarks
83	140	2	None	65.6	20	55.0	None Taken	15.0	A	20	- - -	0	0	
84	110	4	None	58.7	90	48.8	None Taken	19.0	E	25	19.0	43	1.75	Mine hit and flipped over.
85	160	7	None	58.7	90	48.8	None Taken	16.0	E	36	16.0	36	0	Half of mine face covered with soil.
86	160	6	None	65.6	90	55.0	None Taken	20.0	E	53	20.0	53	0	Mine totally covered with loose soil.
87	140	6	None	65.6	90	55.0	None Taken	27.5	B	77	27.5	77	0	Mine totally buried with loose soil.
88	150	7	None	96.6	90	77.0	None Taken	16.0	A	15	16.0	15	1.5	Mine totally buried with loose soil.
89	165	6	None	96.6	90	77.0	None Taken	18.0	A	20	18.0	20	3.0	
90	150	5	None	65.6	50	55.0	None Taken	16.0	D	90	16.0	85	0	
91	155	6	None	65.6	50	55.0	None Taken	26.0	C	63	26.0	63	0.6	Mine totally covered with loose soil.
92	100	5	None	65.6	20	55.0	None Taken	5.0	A	10	0	0	0	
93	140	7	None	65.6	20	55.0	None Taken	7.5	C	25	0	0	0	

[a]Impact velocity and spin rate were measured from high-speed photography data on all calibration tests. For other tests, impact velocity was estimated from calibration curves.

[b]See Figure 2.

Dry Lean Clay. The trafficability cone penetrometer readings taken to the depth of mine penetration ranged from 300 to over 750, the average being 550. The dynamic cone blows (blows/15 cm) ranged from 18 to 50 with an average of 27.5. Samples taken from the surface to a depth of 15 cm yielded values of mass density and moisture content of 1.75 g/cm^3 and 15 percent, respectively, for the calibration tests and 1.79 g/cm^3 and 15 percent, respectively, for the remaining tests in dry lean clay. The liquid limit was 50, the plastic limit was 26, and the plasticity index was 24.

Wet Lean Clay. Trafficability cone penetrometer readings taken to the depth of mine penetration ranged from 58 to 300, the average being 156. The low number of blows for the dynamic penetration at 15 cm of depth was two, the high seven, and the average five. At the 30 cm depth the total number of blows ranged from eight to 15 with an average of 11. Mass density of the 0 to 30 cm depth was 1.84 g/cm^3 and moisture content was 18 percent. The Atterberg limits were the same as those for the dry lean clay.

Wet Fat Clay. Trafficability cone penetrometer readings taken to the depth of mine penetration ranged from 65 to 110 with an average of 95. The dynamic cone penetrations for the 15 cm depth ranged from one to seven blows, the average being five; for the 30 cm depth the blows ranged from six to 14 with an average of nine. Several samples were taken from three layers (0 to 15, 15 to 30, and 30 to 45 cm) to determine density and moisture content because these parameters change with distance from the river channel. Densities ranged from 1.70 to 1.79 g/cm^3 and moisture content from 28 to 33 percent. The Atterberg limits were as follows:

	0 to 15 cm	15 to 30 cm	30 to 45 cm
Liquid Limit	91	98	77
Plastic Limit	33	36	28
Plasticity Index	58	62	48

4. ANALYSIS OF DATA

The analysis of the data was directed toward (a) deriving a calibration curve for the air gun that related the tank pressure to the impact velocity and spin rate of the Gator mine, and (b) deriving relations of emplacement performance, impact condition (velocity and angle of incidence upon impact), and the quantitative descriptions of soil strength (trafficability or dynamic cone index). The theoretical study indicated that in worst-case conditions the mine would be emplaced excessively deep in soil capable of supporting heavy tracked vehicles. For this reason, it was suspected that in realistic delivery modes, i. e., when the mine was delivered spinning, and at various impact angles certain soils would still permit excessive penetraton.

Because of the large number of variables, it was recognized at the outset that the performance of the mine at all possible impact angles, impact attitudes, and impact velocities could not be adequately defined empirically. The analysis was directed, therefore, toward defining general trends of performance and identifying threshold values of soil strength beyond which excessive penetration would not occur. The analysis was guided by the question: Do the terrain conditions that result in inadequate implantation occur in relatively large land areas of the world?

a. Calibration

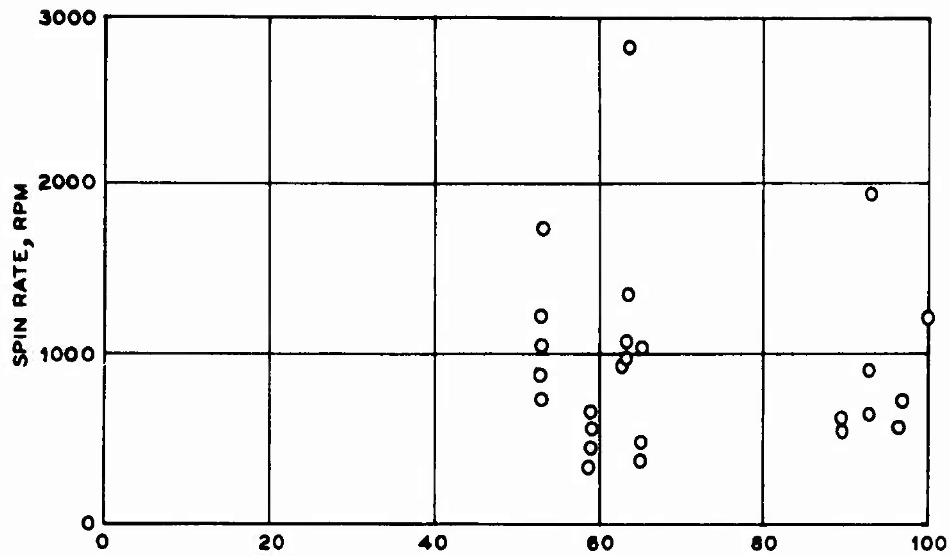
Of the 93 shots in the test program (Table 3), 25 shots fired at an incidence angle of 90 degrees were recorded on film using high-speed movie equipment. The relevant frames of high-speed movie film were studied sequentially to derive the revolutions per minute (rpm) of the mine (enclosed in the sabot) as the sabot left the barrel. Also, the frames showing the mine impacting the ground were studied sequentially to establish the velocity in meters per second of the mine on impact. These values (spin rate and impact velocity) were plotted versus the tank pressure in N/cm^2 to establish the calibration curve shown in Figure 11. Figure 11a shows considerable scatter in the spin rate. For this reason, it was decided that estimating spin rate from the 25 calibration shots would not be accurate. While the mechanism was intended to produce a rotational speed that was directly proportional to trajectory velocity, the mechanism failed to work as anticipated. In practice, there was no obvious relation between trajectory velocity and spin rate. Spin rates actually varied from 308 rpm (at a trajectory velocity of 45.15 meters per second) to 2791 rpm (at a trajectory velocity of 54.18 meters per second). The average spin rate was approximately 966 rpm (Figure 11a and Table 3). Figure 11b shows a good correlation between impact velocity and tank pressure, and it appeared that a reasonable estimate of impact velocity could be made from the tank pressure readings.

It is suspected that the addition of the splitter assembly adversely affected the spin rate of the sabot. However, the air pulse moving the sabot was probably not loading the sabot identically each time, and design modification in both the sabot and barrel that would ensure more uniform loading of the sabot for a longer period of time would permit a better correlation of spin rate and tank pressure.

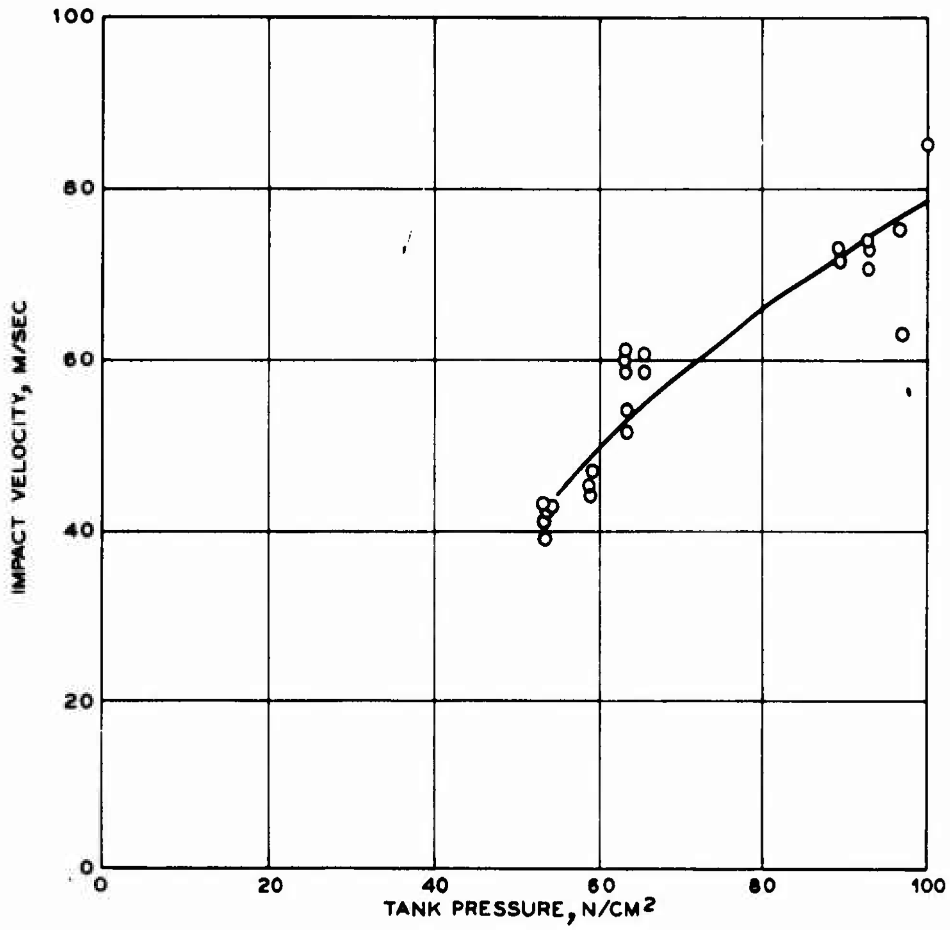
b. Performance Evaluations

The data developed in the test program and listed in Table 3 were studied to develop an understanding of Gator mine penetration performance as a function of impact velocity, orientation of the mine at impact (attitude), impact angle, and soil strength. Two penetration depths are defined in the analysis of data (Figure 2). The initial penetration depth is the depth prior to bounce or roll-out, and the final penetration depth is the depth at which the mine comes to rest. Penetration performance of the Gator mine was judged acceptable only when the mine came to rest with a 14.6- by 14.6-cm surface approximately parallel with the ground surface (within 30 degrees) and when the final penetration depth in this position was less than the height of the mine (5.8 cm).

(1) Effects of Impact Velocity. Penetration results, as a function of impact velocity for dry lean clay, wet lean clay, and wet fat clay are shown for the various impact attitudes at an impact angle of 90 degrees in Figure 12. The impact attitudes A, B, C, D, and E were obtained from the mine print after impact (Figure 10) and were documented in photographs.



a. SPIN RATE VS TANK PRESSURE



b. IMPACT VELOCITY VS TANK PRESSURE

Figure 11. Results of Calibration Test for Gator Air Gun

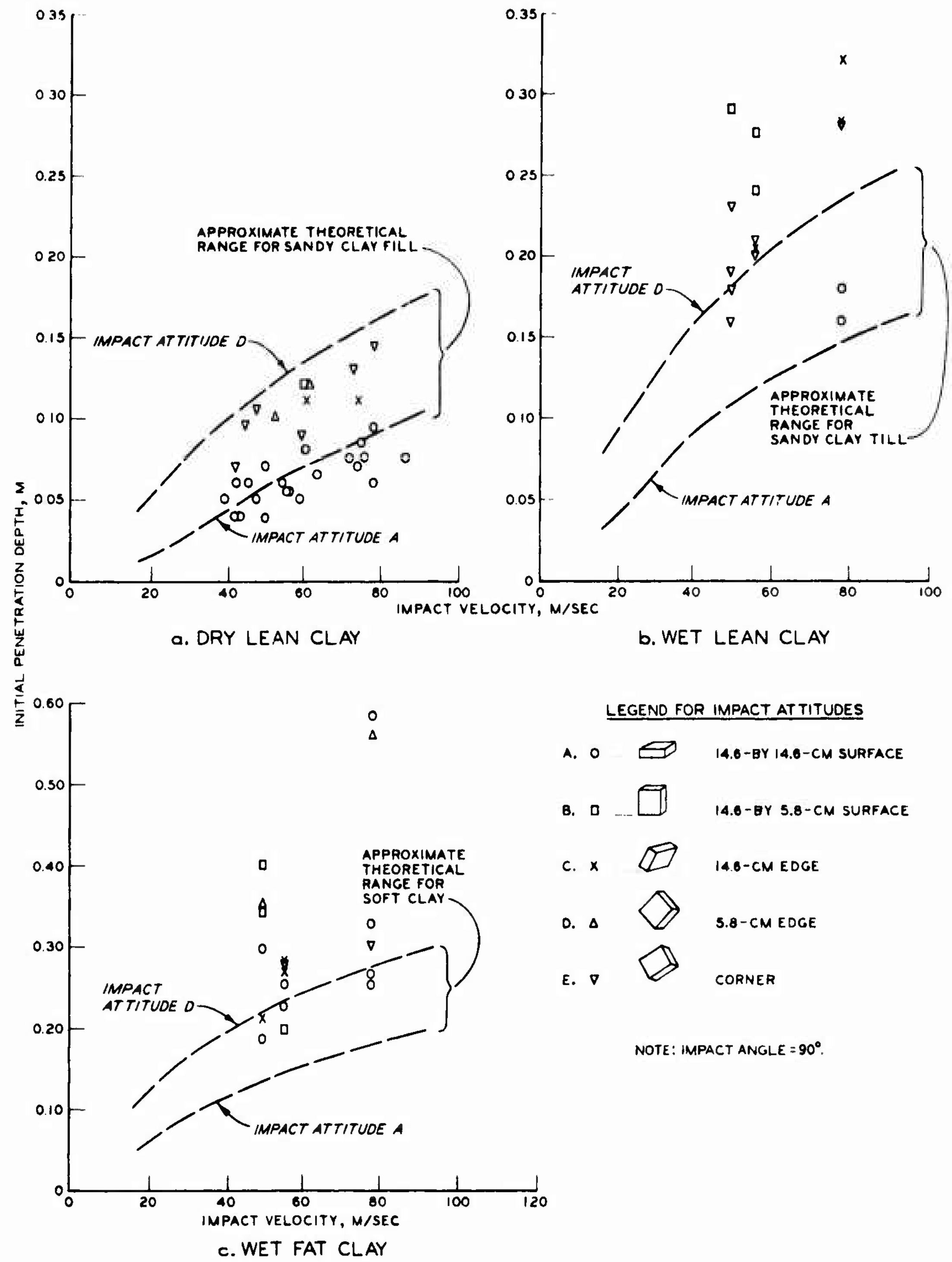


Figure 12. Field Study Penetration Results: Effects of Impact Velocity

The slope angles for attitude A included 0 ± 22.5 degrees; for attitudes B and D, 90 ± 22.5 degrees; and for C and E, 45 ± 22.5 degrees. As was found in the theoretical study, impact attitude has a tremendous effect on emplacement; however, impact attitudes cannot be positively controlled in deployment. Therefore, all impact attitudes must be evaluated. In general, penetration will increase with an increase in impact velocity. This tendency is depicted in all three plots in Figure 12.

The deepest penetration was obtained in wet fat clay, the shallowest in dry lean clay, and intermediate in wet lean clay. The shallowest penetrations are rather consistently associated with impact attitude A, especially in the firmer soils. However, in the softer soils the data points do not cluster in as regular a pattern as for the firmer soils. The soils in the theoretical and empirical studies were not identical, so good correlation could not be expected; however, the trends should be similar. The soils from the theoretical study selected for comparison with the dry lean clay, the wet lean clay, and the wet fat clay are the sandy clay fill, the sandy clay till, and the soft clay, respectively. Both the lean clay and the sandy clay are CL soils, and both the wet fat clay and soft clay are CH soils. The approximate theoretical range of penetration depths (i. e., the range between impact attitudes A and D) for the comparison soils from Figure 3 are shown in Figure 12. Figure 12 shows that the wet lean clay penetration values lie in a band slightly above those of the sandy clay till, and the dry lean clay penetration values lie in a band that is nearly the same as that of the sandy clay fill. The wet fat clay penetration values lie in a band that is slightly above that shown for the soft clay.

In general, the comparison at an impact angle of 90 degrees shows that the field study would indicate worse mine performance than that indicated by the theoretical study. For example, delivery of the mine was unacceptable for the wet fat clay and wet lean clay over the impact velocity range of 49 to 77 meters per second, since the mine penetrated too deeply (the mine was completely buried) and did not roll out of the impact hole. Further, for dry lean clay for the 39 to 86 meters per second range, only a few shots at impact velocities less than 60 meters per second were acceptable according to established criteria. Satisfactory performance was shown by 12 of the 32 shots and these shots were at impact attitude A (14.6- by 14.6- cm surface) with a penetration depth of less than 5.8 cm.

(2) Effects of Impact Angle. Penetration results for a firing tank pressure of 65.6 N/cm^2 (approximately equivalent to 55 meters per second or slightly greater than the free-fall velocity when the mine is deployed tactically) as a function of impact angle for dry lean clay, wet lean clay, and wet fat clay are shown in Figure 13. Also shown for comparison is an estimate of penetration derived by multiplying sin θ (where θ is the impact angle) by 90-degree penetration values obtained for the comparison soils for impact condition B. This calculation is based on the assumption that the normal component of force is responsible for mine penetration. The deepest initial penetration was measured at a 90-degree impact angle, and it decreases as the impact angle decreases. These measured data follow the same general trend as found in the theoretical study and indicate that the mine delivery system should be designed to deliver the mines at a relatively small impact angle. If the impact angle is too small, however, the mine will skip instead of tumble, and this could result in a wider distribution of the mines than desired.

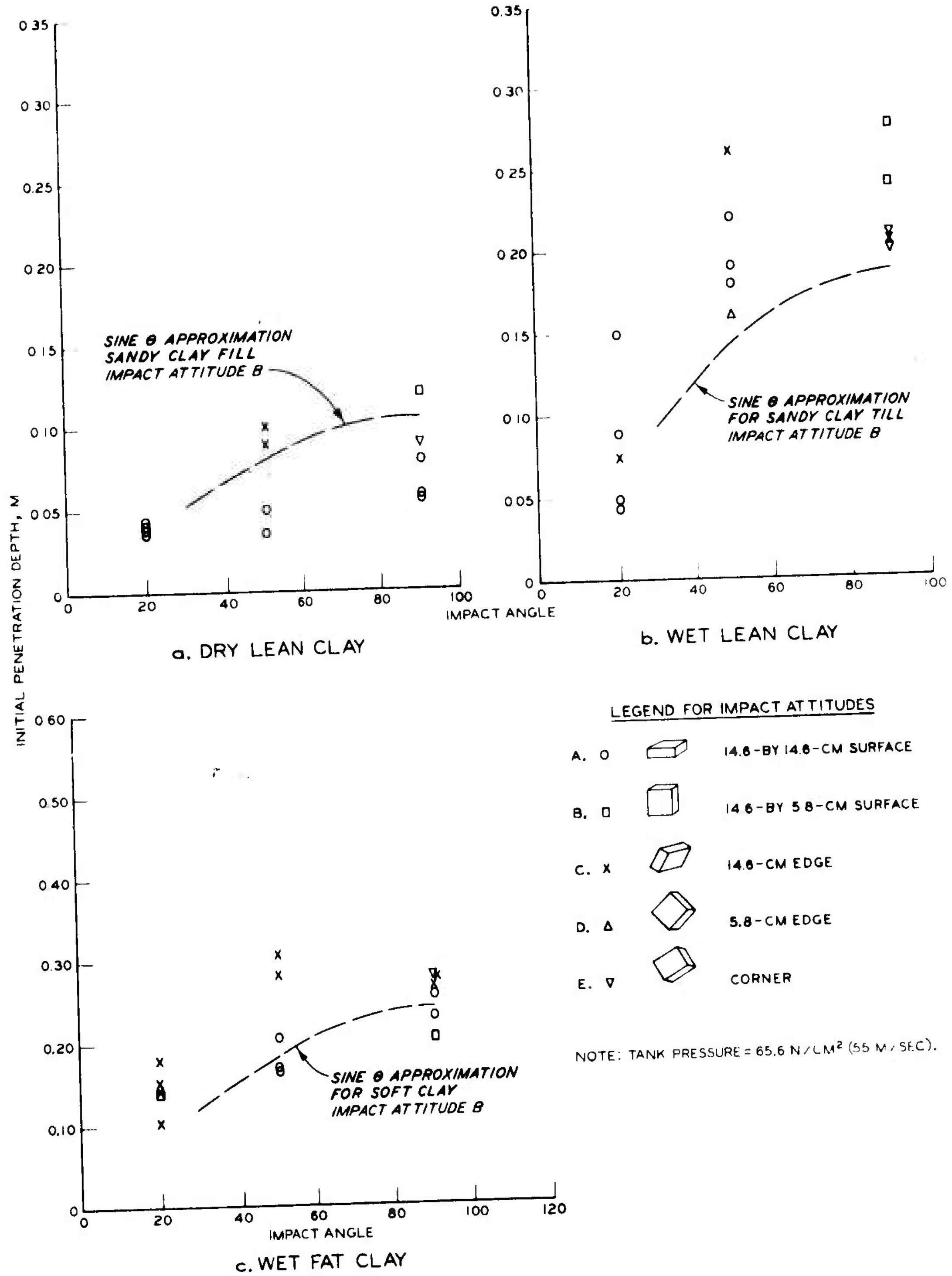


Figure 13. Field Study Penetration Results: Effects of Impact Angle

(3) Initial and Final Impact Attitudes. If the initial penetration is sufficiently shallow, emplacement performance of the mine can be judged on this factor alone; however, for activation the final, or at-rest, penetration and attitude of the mine is of paramount importance. A means for estimating (theoretically) the final penetration of the mine is not available, but a relation among initial penetration, impact angle, and final penetration and attitude would be useful. For this reason, initial depth of penetration was plotted versus final depth of penetration for dry lean clay, wet lean clay, and wet fat clay (Figure 14). Data from all 93 test firings were used in the preparation of the figures; therefore, all impact velocities are represented. The following tabulation (taken from Table 3) shows that most firings were at an impact angle of 90 degrees.

	Number of Firings		
	Impact Angle		
Material	90 Degrees	50 Degrees	20 Degrees
Dry Lean Clay	32	4	4
Wet Lean Clay	15	5	5
Wet Fat Clay	18	5	5
Totals	65	14	14

The mines in all the 20-degree and 50-degree impact angle shots in the dry lean clay (Figure 13a) rolled out of the initial penetration hole regardless of impact attitude. Seven of the eight mines came to rest on the 14.6- by 14.6-cm surface (satisfactory at-rest angle) and one came to rest on the 14.6- by 5.8-cm surface (unsatisfactory at-rest angle). Seven of the mines in the 90-degree impact angle shots in dry lean clay rolled out of the impact hole (one came to rest on the 14.6- by 5.8-cm surface) and five penetrated to less than 5.8 cm. This means that 20 of the 40 shots penetrated to less than 5.8 cm. Also, 31 of the 40 shots came to rest at angles of less than 30 degrees. In three cases (shots 24, 25, and 68), penetration was satisfactory but the final at-rest angle exceeded acceptable limits. Therefore, totally acceptable implacement conditions occurred in only 17 of the 40 firings.

Figure 15 shows final mine positions representative of the final positions of the mines observed in the dry lean clay. Figures 15a corresponds to test 25 in Table 3. The mine had an impact velocity of 45.15 meters per second and penetrated 6 cm. It was fired at 90 degrees from horizontal and bounced a distance of 0.13 meter after impact. The mine came to rest, as shown, on the 14.6- by 5.8-cm side (at-rest angle = 90 degrees), which makes this final position unacceptable. Figure 15b corresponds to test 57 in Table 3. In this case the mine had an impact velocity of 55.0 meters per second and penetrated 5 cm upon impact. It was fired at 50 degrees from the horizontal and bounced 4.0 meters after impact. An overburden of 0.2 cm was measured on the surface, which would degrade its performance significantly. Figure 15c corresponds to test 60 in Table 3. The mine impacted the ground at 48.8 meters per second and penetrated 4 cm. It was fired at 90 degrees from horizontal and did not bounce after impact. Its final position is acceptable.

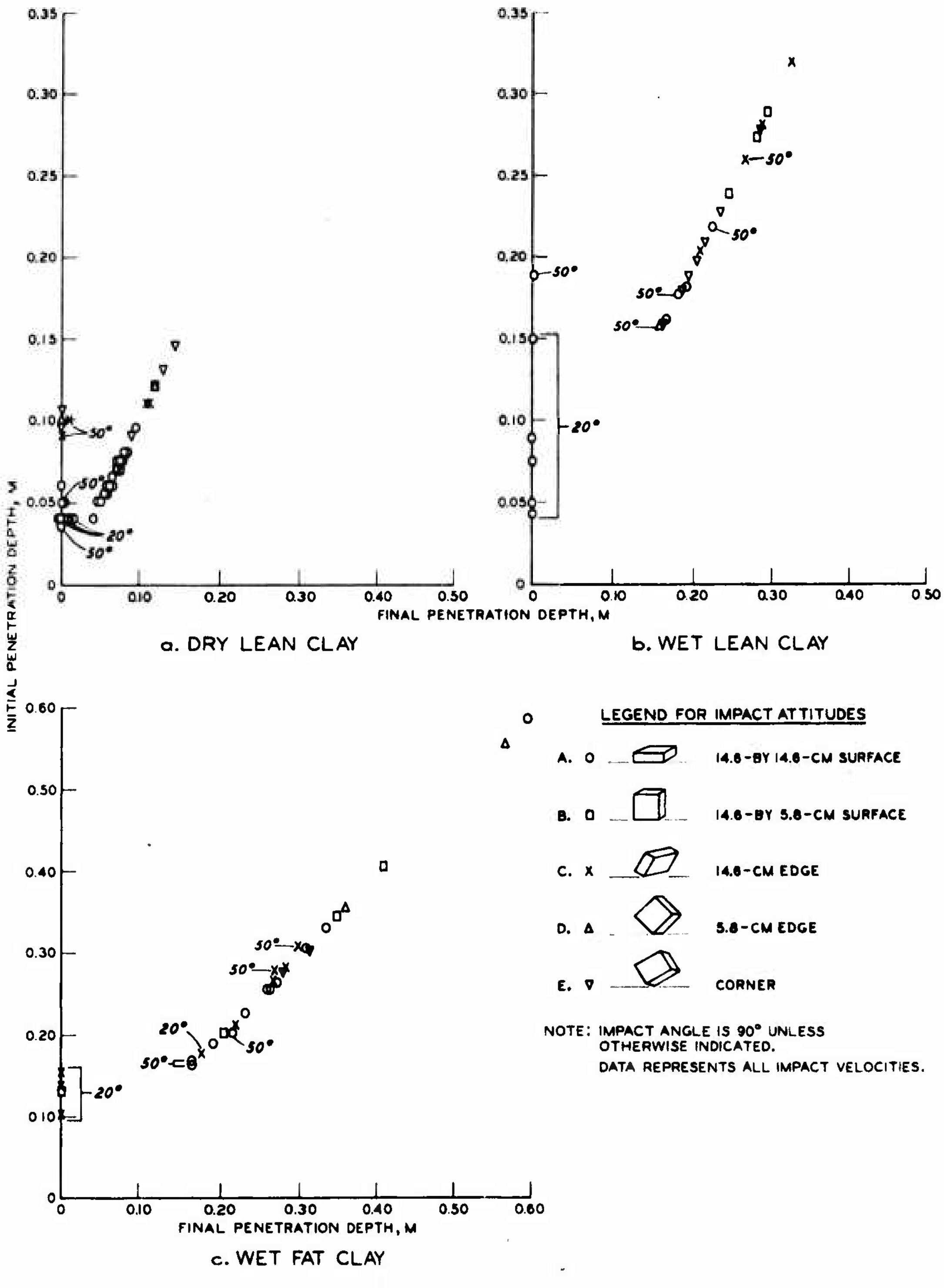


Figure 14. Field Study Penetration Results: Initial Penetration Depth Versus Final Penetration Depth

a. Test No. 25, Table 3

b. Test No. 57, Table 3

c. Test No. 60, Table 3

d. Tèst No. 64, Table 3

Figure 15. Examples of the Final Position of the Gator Mine in Dry Lean Clay

Figure 15d shows the final position of the mine in test 64 in Table 3. The mine's impact velocity was 77.0 meters per second, and it penetrated 14.5 cm. It was fired at 90 degrees from horizontal and stuck, as shown, on impact. Its final position was not acceptable.

Figure 14b shows that the emplacement performance of the Gator mine in the wet lean clay was not good. Only the tests at 20-degree impact angle showed consistently acceptable results. However, one shot fired at an angle of 50 degrees did not remain embedded in the ground. In all cases the mines, on impact, exceeded the critical depth; however, they rolled out in the cases mentioned above, and the mines in all the 20-degree shots came to rest on the 14.6- by 14.6-cm surface (so that the at-rest angle was satisfactory). The mine in the one 50-degree shot came to rest on the 14.6- by 5.8-cm surface (at-rest angle was 90 degrees and unacceptable). The mines in all the rest of the 50-degree shots and in all the 90-degree shots stayed in the impact hole and penetrated excessively (i. e., the critical depth was exceeded). Figure 16 depicts representative final positions of the mines. Figure 16a shows the results of a firing in which the impact angle and velocity were 90 degrees and 48.8 meters per second, respectively. The figure corresponds to test 75 in Table 3. The emplacement was not satisfactory because of the resulting at-rest angle of the mine and excessive penetration (18 cm). Figure 16b shows another unsatisfactory emplacement (test 79, Table 3). The mine had an impact velocity of 55.0 meters per second and penetrated 19 cm. It was fired at 50 degrees from the horizontal and bounced at right angles to the line of fire for a distance of 0.50 meter. It landed as shown on the 14.6- by 5.8-cm side. Figure 16c depicts a large crater made by the mine on impact (test 80, Table 3). In this shot the mine had an impact velocity of 55.0 meters per second and penetrated 22 cm. It was fired at 50 degrees from the horizontal, and did not bounce after impact; its final position was on the 14.6- by 5.8-cm side and was therefore unacceptable. Figure 16d shows satisfactory emplacement (test 83, Table 3). In this shot the mine had an impact velocity of 55.0 meters per second and penetrated 15 cm. It was fired at 20 degrees from the horizontal and bounced at right angles to the line of fire for a distance of 0.45 meter.

Figure 14c shows the results of the tests conducted in the wet fat clay. In this soil condition four of the five shots at the 20-degree impact angle rolled out of the initial impact crater even though the critical depth was exceeded; these four shots had satisfactory at-rest angles. The one remaining shot at 20-degree, the five shot at 50-degree, and the 18 shots at 90-degree impact angles resulted in penetration depths that exceeded the critical depth and the mines penetrated excessively (i. e., they stayed in the impact holes). Figure 17 illustrates four examples of the final resting positions of the mines in this soil (tests 31, 26, 43, 46, Table 3, respectively). Figure 17a shows the results of the mine (fired at an angle of 90 degrees) impacting the ground at a velocity of 77 meters per second. The mine penetrated 55.9 cm; it struck the ground on the 5.8-cm edge and did not bounce. For the shot in Figure 17b, the mine had an impact velocity of 48.8 meters per second and penetrated 30.5 cm. Impact was on the 14.6- by 14.6-cm surface. Figure 17c shows the results of the mine impacting the ground at an angle of 50 degrees and at 55 meters per second. It

a. Test No. 75, Table 3

b. Test No. 79, Table 3

c. Test No. 80, Table 3

d. Test No. 83, Table 3

Figure 16. Examples of the Final Position of the Gator Mine in Wet Lean Clay

a. Test 31, Table 3

b. Test 26, Table 3

c. Test 43, Table 3

d. Test 46, Table 3

Figure 17. Examples of the Final Position of the Gator Mine in Wet Fat Clay

penetrated 16.5 cm and did not bounce; however, it slid a distance of 0.30 meter. Figure 17d shows a crater resulting from the mine impacting the ground at a velocity of 55 meters per second and at an angle of 20 degrees from the horizontal. The mine penetrated a depth of 15.2 cm and then bounced a distance of 2.51 meters. The mine landed with the face clear (no overburden), constituting a satisfactory emplacement.

In a significant number of tests, the mine came to rest with an at-rest angle of 90 degrees (i. e., the mine came to rest on the 14.6- by 5.8-cm surface). Out of 25 shots in which the mine bounced out of its impact crater, three shots resulted in an at-rest angle of 90 degrees. It appears that a simple modification to its shape would make the mine unstable in the 90-degree position on level ground and would cause it to fall to the 0-degree position (i. e., the mine resting on the 14.6- by 14.6-cm surface). Some examples of such modification (Figure 18) are:

- Add a bead around the middle of the mine.
- Bevel the edges so that mine cannot stand squarely.
- Change the cross-sectional shape from that of a rectangle with alternately rounded corners to that of a parallelogram with nonperpendicular sides.

These modifications would have to be engineered so that the aerodynamic characteristics of the mine would not be adversely affected.

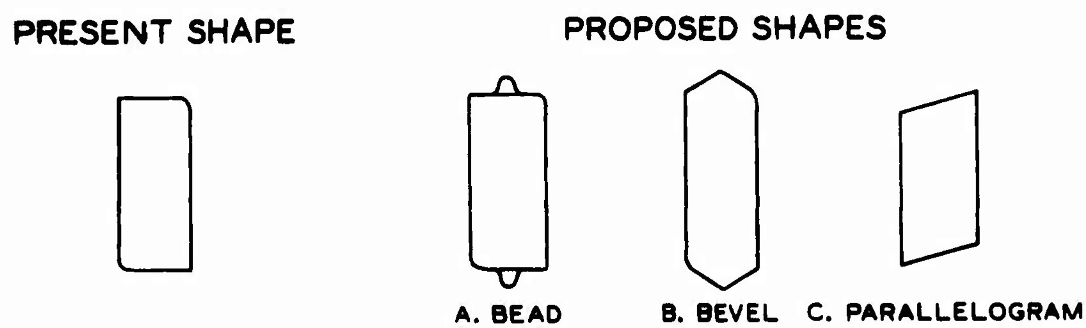


Figure 18. Change of Mine Cross-Sectional Shape to Improve At-Rest Angle Characteristics

(4) Summary. It is apparent from the analysis of the data discussed herein that poor emplacement can be expected in many natural soil conditions. The penetration performance from the air gun test can be expected to be slightly worse than if the mine were delivered in an operational mode, i. e., from high-performance aircraft, because the spin rate for these air gun tests was not up to the expected value under terminal velocity conditions (2500 to 3000 rpm) when the mines are delivered from aircraft. If the mine had a spin rate reaching 3000 rpm, it may have been possible for the mine to roll out of the hole in even more of the shots (including those at

90-degree angles of incidence). Even so, the analysis indicates that the performance of the mine must be correlated with soil parameters that have been mapped worldwide to answer the question: do the terrain conditions that result in poor emplacement occur often in relatively large land areas of the world? The terrain parameters measured during the field test program that could be used as indicators of penetration performance were the dynamic cone index and the trafficability cone index. The relation of these strength parameters to penetration performance is discussed in the following paragraphs.

c. Dynamic Cone Index (DCI) Results

Since the dynamic cone penetrometer has been used successfully in penetration studies, a reasonably good correlation of dynamic cone index and penetration performance, as defined by initial depth of penetration of the mine, was expected. Plots of initial penetration depth versus the reciprocal of dynamic cone index of lean and fat clay soils, at a firing tank pressure of 65.6 N/cm^2 (approximately equivalent to an impact velocity of 55 meters per second), are shown for impact angles of 20, 50, and 90 degrees in Figure 19. For the soils studied, the initial penetration depth increases (for a given impacting surface and impact angle) as 1/DCI increases. In effect, as the soil strength increases, the number of blows required to move the penetrometer down 15.24 cm into the ground increases and the penetration decreases. The quantity of 1/DCI is convenient for these plots since it appears to linearize the data and display the impacting surfaces in increasing order of penetration. Also, the slopes of the lines appear to be related to the impact angle. For example, the slopes of the lines through the data collected for impacting on the 14.6- by 14.6-cm surface are 66.7 percent, 53.3 percent, and 20.0 percent for impact angles of 90, 50, and 20 degrees, respectively. If the slope at 90 degrees is used as a reference and multiplied by sin 50 degrees and sin 20 degrees, the resulting values are 51.1 percent and 22.8 percent, respectively, a difference of 3 percent or less. Thus, for this set of data it appears that the effect of the impact angles can be approximated by the simple sine function. It is emphasized that these empirical results are for lean and fat clay soils under specific moisture conditions. Extrapolation of the results is subject to error. Relations such as shown on Figure 19 should be sought for different soil conditions, especially for cohesionless soils.

d. Trafficability Cone Index (CI) Results

Although reasonable correlations were found between 1/DCI and the initial depth of penetration, the relation could not be used conveniently to estimate mine performance in world conditions, because 1/DCI has not been mapped on a worldwide basis. The world has been mapped in terms of the trafficability cone index (Reference 7) and, therefore, correlations of final penetration and this parameter were sought.

Reference

7. Meyer, M. P. and Bohnert, W. P., Jr., "Worldwide Strength Conditions of Surface Materials," Miscellaneous Paper M-70-2, Apr 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

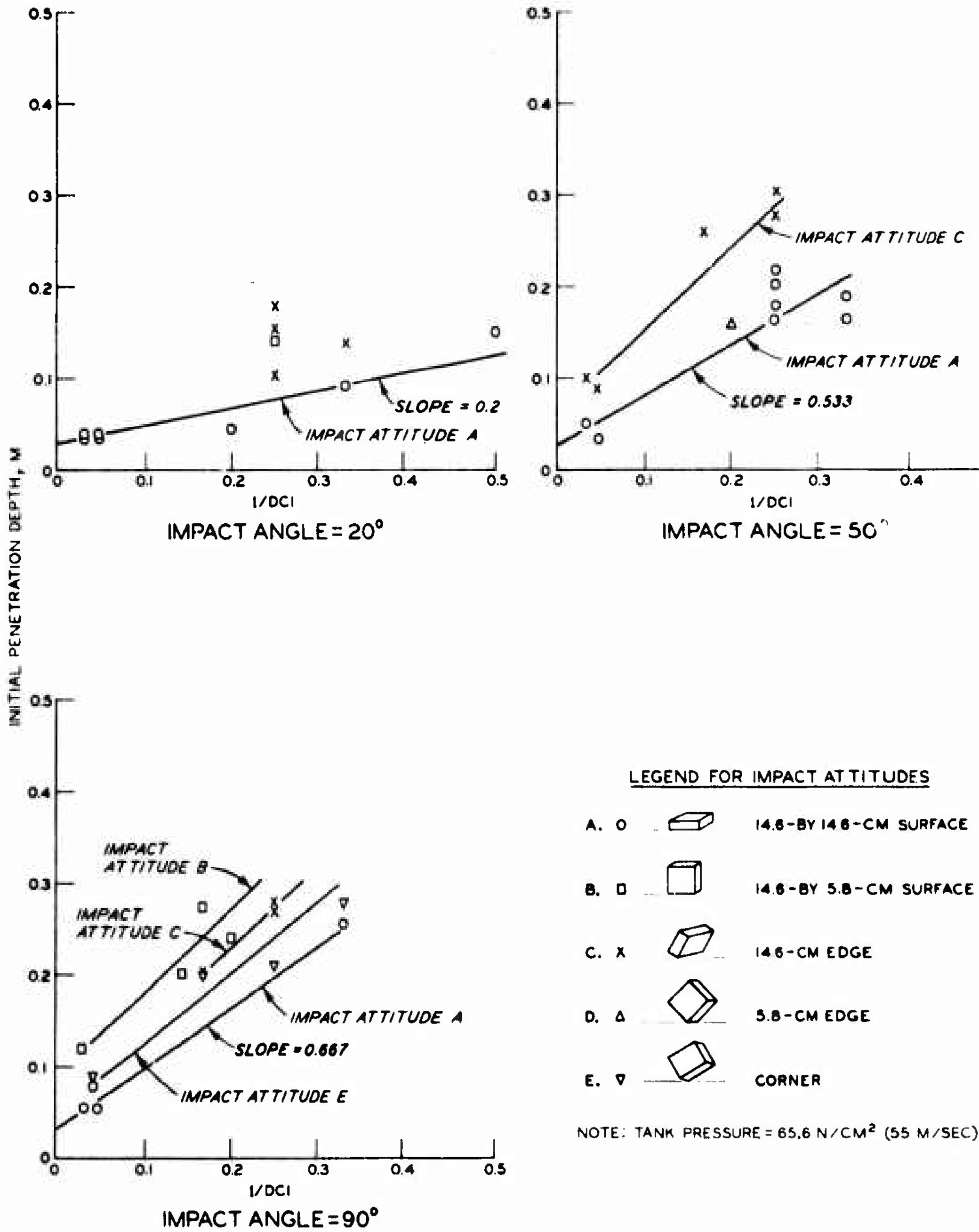


Figure 19. Field Study Penetration Results: Effects of Dynamic Cone Index of Lean and Fat Clay Soils

Plots of final penetration depth versus cone index at a firing tank pressure of 65.6 N/cm^2 (approximately equivalent to an impact velocity of 55 meters per second) are shown for impact angles of 20, 50, and 90 degrees in Figure 20. At a 20-degree impact angle all shots but one resulted in acceptable penetration in the lean and fat clay soils for a cone index greater than approximately 20. Although there are no results shown at impact angles of 20 degrees for a cone index less than 25, it is believed that very few of the shots in a clay soil with a cone index of less than approximately 20 will yield acceptable penetration performance. For the 50-degree angle of incidence, all the shots in clays with cone index values less than 150 resulted in excessive penetration; clays with cone indexes of 200 or greater were generally acceptable. For the 90-degree angle of incidence, all but two of the shots in the clays resulted in excessive penetration for cone index values of up to 750. It is believed that in a majority of cases at 90-degree angle of incidence, penetration will be acceptable in clay soils with a cone index above 750. These results can be used to approximate a cone index requirement (i. e., acceptable performance can be expected for cone indices of 20, 150, and 750 if the incidence angles are 20, 50, and 90 degrees, respectively) for satisfactory penetration performance in clay (CL and CH) soils at an impact velocity of 55 meters per second, as shown in Figure 21.

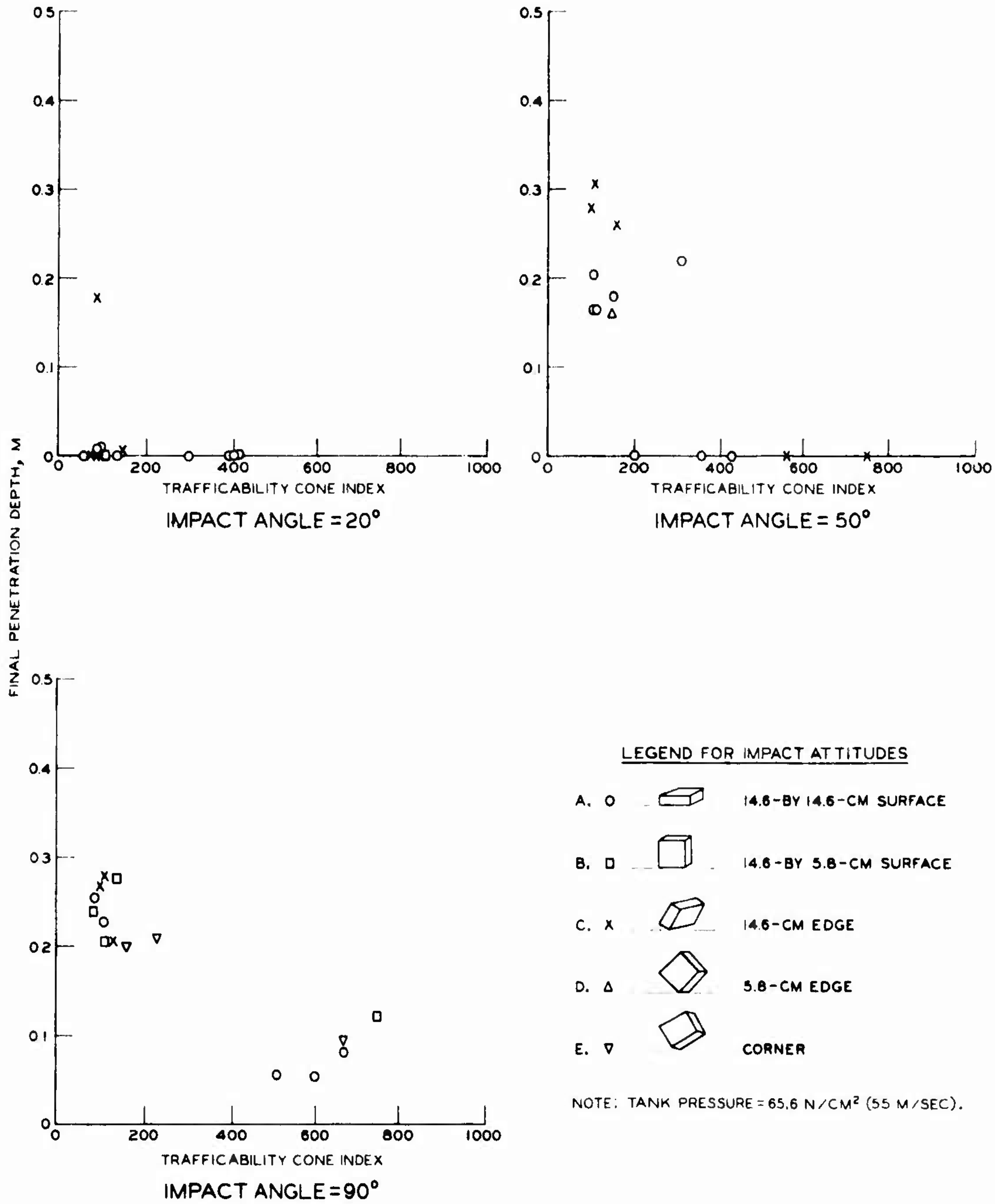


Figure 20. Field Study Penetration Results: Effects of Trafficability Cone Index of Lean and Fat Clay Soils

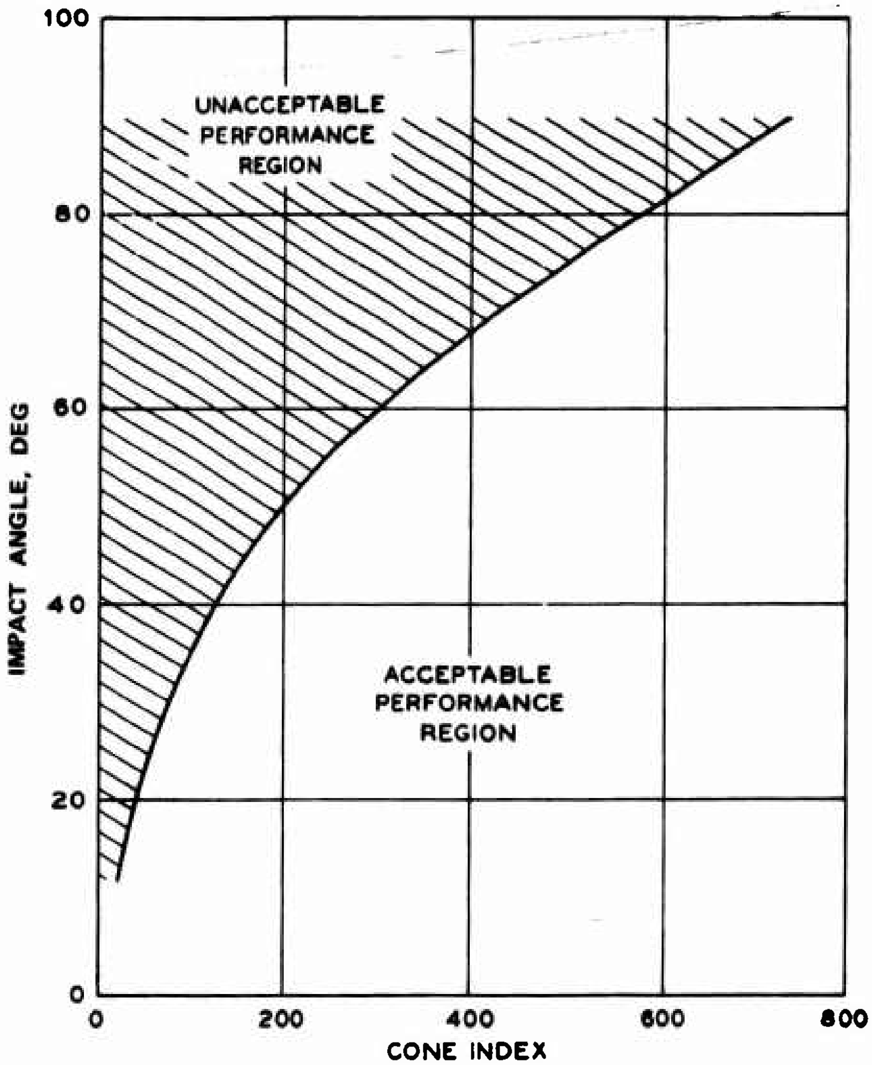


Figure 21. Gator Mine Penetration Performance in Lean and Fat Clay at an Impact Velocity of 55 Meters per Second

SECTION IV

ESTIMATED WORLDWIDE PERFORMANCE

The gross relation shown in Figure 21 can be used as an aid in interpreting the maps in Reference 7 to estimate penetration performance of the Gator mine in world conditions. The interpretation is not straightforward because the cone index values in the reference do not adequately encompass the ranges shown in Figure 21, i. e., the cone index mapping classes in Reference 7 are 0 to 45, 45 to 47, 75 to 150, and greater than 150. The mine will have excessive penetration in cohesive soils having a cone index of 750 or less if the mine is delivered at an angle of 90 degrees and an impact velocity of 55 meters per second. Data showing the distribution of soil with a cone index value of 750 worldwide are not available. However, it is emphasized that soils within that strength range (0 to 750) are very common. For this reason, if the mine were delivered at 55 meters per second and at an impact angle approaching 90 degrees, a clearing charge would be absolutely necessary. Further, it can be expected that unacceptable performance will result from many of the mines delivered at impact angles less than 90 degrees.

The distribution of impact angles resulting from a canister of mines being delivered in a tactical mode is not known. For this reason it does not appear prudent to attempt to estimate emplacement performance for narrow classes of impact angles; however, Figure 21 shows that if the mine is delivered at impact angles equal to or less than 45 degrees, it will be emplaced adequately in soils that have a cone index of 150 or greater. It is reasonable to assume that many of the mines will impact at angles less than 45 degrees and therefore it is useful to determine (from the maps in Reference 7) the percentage of the world with soil strengths greater than 150 cone index. A direct correlation of penetration performance and cone index of greater than 150 will result in a conservative estimate of performance (i. e., performance poorer than will actually occur will be shown). Furthermore, the estimate of the percentage of the world in which the mine would perform adequately will be conservative. The reasons for this are at least twofold. First, vegetation assemblages will often occur on the land mass where mines are delivered, and the vegetation stems and branches will tend to deflect the mines such that the mine impact velocity will be decreased, thereby decreasing penetration significantly. Second, soils having a cone index of less than 45 (Reference 8) would deny vehicle movement and deployment of mines would be unnecessary. For this reason the total area denied to heavy tracked vehicles could theoretically be computed as the sum of the areas that have a cone index of less than 45 (untrafficable) and greater than 150 (mineable). It should be noted that because heavy tracked vehicles can negotiate soils exhibiting a cone index of 45 or greater

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Reference

8. Meyer, M. P. and Knight, S. J., "Trafficability of Soils, Soil Classification," Technical Memorandum No. 3-240, Sixteenth Supplement, Aug 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

(Reference 8) there is a range of soil strengths (150 to 45) in which vehicles can operate, but in which mines would become embedded too deeply (for impact velocity of 55 meters per second and angle of 45 degrees, respectively) for the mines to be effective. A more realistic estimate of the performance of the mine (impacting velocities of 55 meters per second and angles of 45 degrees) in soils having a cone index in the range of 45 to 150 was based on both soil strength and vegetation maps. Criteria for interpreting the effects of vegetation were developed from results of previous work accomplished at WES and reported in Reference 9. The interpretation rationale and procedures used to derive the probability that a mine (delivered at an impact velocity equal to or less than 55 meters per second and at an impact angle of 45 degrees) will be emplaced adequately for a given location on the ground is presented in the following paragraphs.

1. INTERPRETATION RATIONALE AND PROCEDURES

a. Worldwide Surface Soil Strength Map

The worldwide surface soil strength map is presented in three parts in Reference 7: North and South America in map 1; Western Europe and Africa in map 2; and Eastern Europe, Asia, and Australia in map 3. As shown in the legend (Figure 22), the predominant strengths of the surface soil in terms of five cone index classes, are presented as a set of three four-month periods of the year. A complex of strength conditions is indicated wherein two or three sets of symbols within a box are allocated to a single map unit (see example in Figure 22). This type of designation depicts the approximate percentage of each set of strength conditions within the map unit in proportion to the area within the box and, for some delineations, a symbolized areal configuration for each set of strength symbols. For example, approximately 65 percent of the area within the map unit shown has strength conditions ACC, and 35 percent has strength conditions ADD in a random distribution.

Figure 23 shows a small portion of the worldwide surface soil strength map (map 2, Reference 7). The probability of successfully emplacing a mine, as interpreted from the map, was predicated on three assumptions:

(1) The mine would be delivered at 55 cm/sec or less and at an impact angle of 45 degrees or less (the mine will be emplaced adequately in any area marked "A", i. e., cone index >150).

(2) The mine has equal probability of landing anywhere in the mapped unit.

(3) The mine has equal probability of being delivered at any time of the year.

Reference
9. Collins, J. G. and Allen, H. H., "Munition Burst Probability as Related to Vegetation, Fuze, and Munition Trajectory Characteristics," Miscellaneous Paper M-73-10, Jun 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONE INDEX OF THE 0- TO 15-CM LAYER OF SURFACE MATERIAL

WESTERN EUROPE AND AFRICA

LEGEND

CLASS	CONE INDEX
A	>150
B	75-150
C	45-75
D	0-45, SOIL
S	0-45, SNOW

STRENGTH CODE	PERIOD OF TIME
AAA	DECEMBER-MARCH
	APRIL-JULY
	AUGUST-NOVEMBER

LAKE

.... POLITICAL BOUNDARY

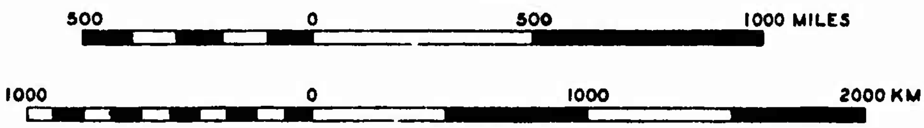
NOTE: TWO OR MORE CODES WITHIN A BOX INDICATE A COMPLEX OF STRENGTH CONDITIONS FOR THE AREA IN PROPORTION TO THE AREAS WITHIN THE BOX.

EXAMPLE

ACC — AVERAGE CI OF 65% OF AREA IS >150 DEC-MAR AND 45-75 APR-JULY AND AUG-NOV.

ADD — AVERAGE CI OF 35% OF AREA IS >150 DEC-MAR AND 0-45 APR-JULY AND AUG-NOV.

SCALES



GOODE'S HOMOLOSINE EQUAL-AREA PROJECTION

Figure 22. Legend for the Surface Soil Strength for Map of the World (Map 2, Reference 7)

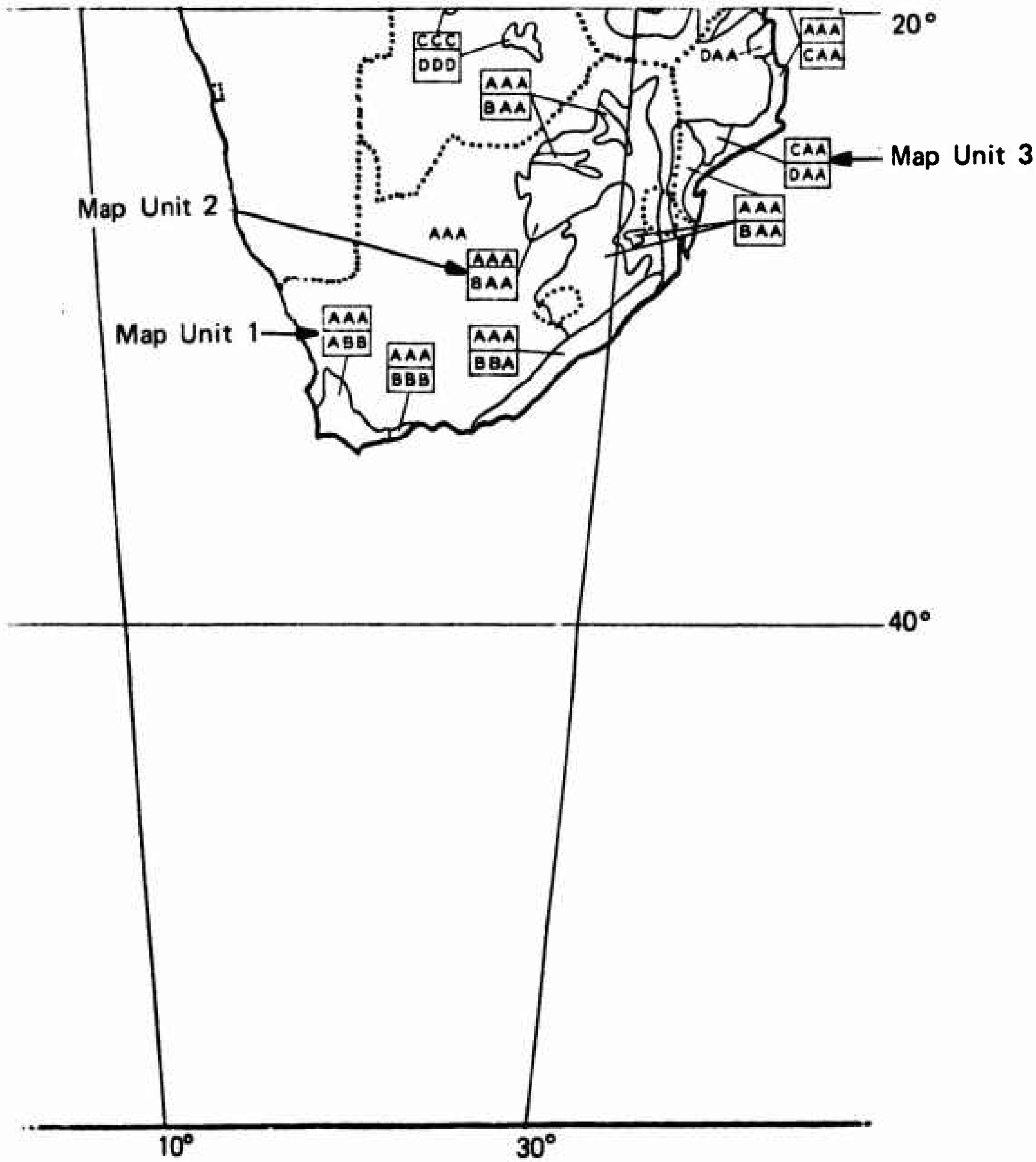


Figure 23. Portion (Southern Tip of Africa) of the Surface Soil Strength Map of the World (Map 2, Reference 7)

The percent probability of successful emplacement can be derived from the legend by computing the percentage of the time each map unit will have a cone index greater than 150. For example, the probability that the area designated AAA/ABB (map unit 1, Figure 23, southern tip of Africa) would permit satisfactory emplacement is computed as follows:

(1) Determine contribution of each symbol in the complex designation. Since the symbol is divided in half, combination AAA occurs over the same amount of area as ABB, and therefore, each individual symbol has equal probability of occurring in the mapped unit.

(2) Calculate probability in percent that a random point in the map would be designated symbol A. Since each symbol has equal weight, the probability is the ratio of the number of A's in the complex to the total number of symbols:

$$P = \frac{4}{6} \times 100 = 67 \text{ percent.}$$

Using the same rationale, the probability that a point in map unit 2, Figure 23, would be designated A is computed by adjusting symbols according to their percentage of occurrence. The upper set occurs in 35 percent of the area and the lower set occurs in 65 percent of the area. The percent probability is then computed:

$$P = 3 \times \frac{0.35}{3} + \frac{2 \times 0.65}{3} = 79 \text{ percent.}$$

b. Worldwide Vegetation Maps

Emplacement performance of the mine can be expected to improve if the mine is delivered in vegetated areas. This improvement is assumed to be directly proportional to the probability of the mine striking a tree branch large enough to change the trajectory of the mine. The basic vegetation maps were prepared by Eyre (Reference 10). All of the main vegetated land areas of the earth are shown in the 10 maps presented in Reference 10. A sample map is shown in Figure 24. Thirty-three major vegetation types are recognized, each being represented by a characteristic symbol. The theoretical climatic climax vegetation, the existing wild vegetation, and that which is known to have existed in the past are shown on the maps.

Worldwide vegetation maps were interpreted to obtain the probability that a mine would strike a branch during descent large enough to result in satisfactory emplacement in any soil in which heavy tracked vehicles could operate, i. e., in areas where the cone index values are greater than 45. Further, if the cone index values are less than 45, excessive mine penetration would probably occur even if the mine bounced off of one or more tree branches. To interpret the maps, the following assumptions are made:

(1) A mine striking a branch of 5-cm diameter or greater will deflect the mine such that it will not penetrate into soils having a cone index of 45 or greater (Reference 11).

Reference

10. Eyre, S. R., Vegetation and Soils, 2nd Ed., Aldine, Chicago, Ill., 1968.

11. Keown, M. P., Stoll, J. K. and Nikodem, H., "Experimental Data on Moment Transfer from an Explosion to a Tree Stem," Technical Report, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

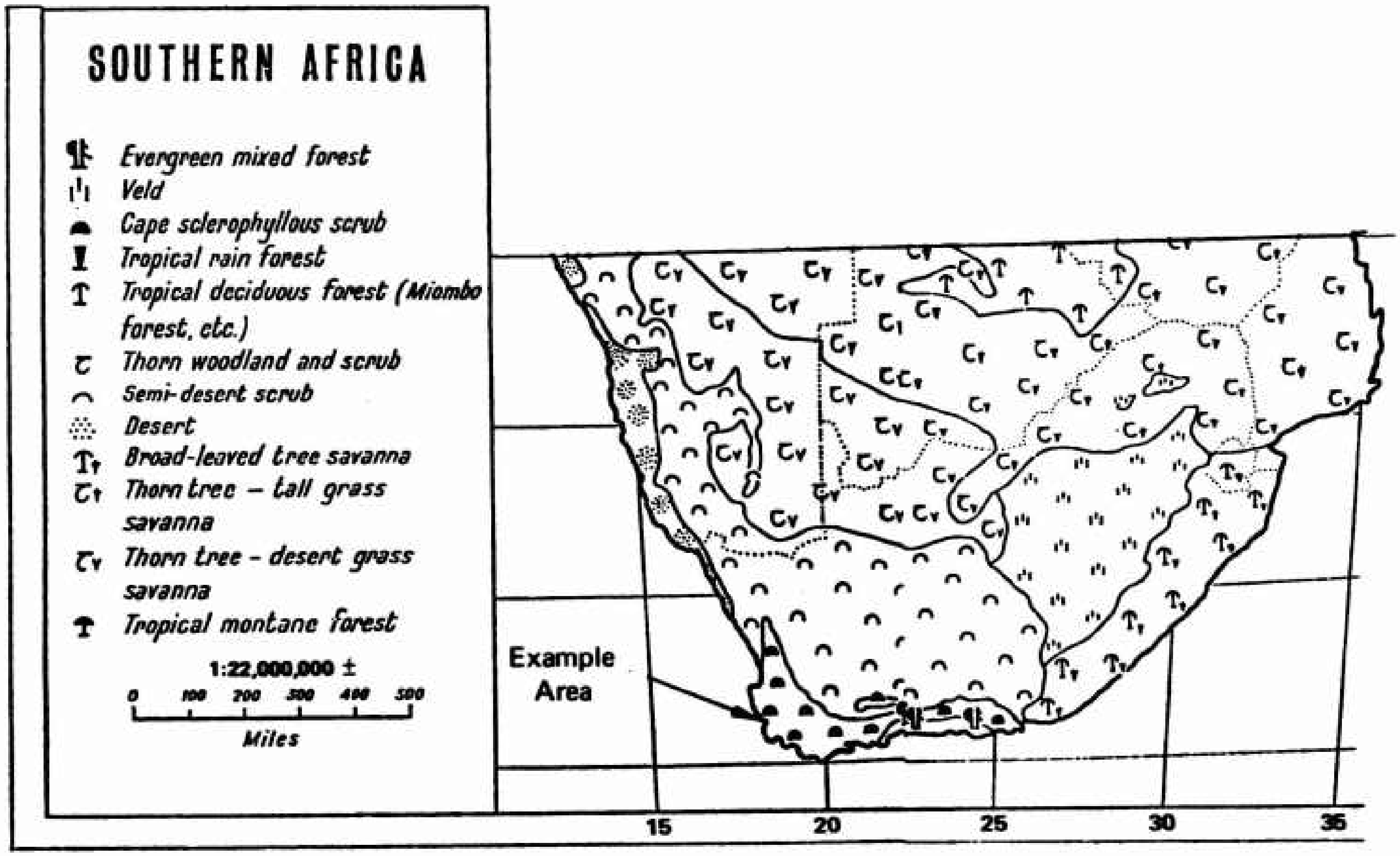


Figure 24. Sample (Southern Tip of Africa) of the Worldwide Vegetation Map (Map 9, Reference 10)

(2) The probability of a mine striking a branch of 5-cm diameter or greater is equal to the cumulative percent area of total vegetation assemblage covered by branches of 5-cm diameter and greater.

(3) Excessive penetration will occur in all areas having a cone index less than 45.

Assumption (1) requires that the world maps be interpreted in terms of the cumulative branch area (stems of 5 cm or greater). This was accomplished by using the presented area versus stem diameter relations given in Reference 9.

The worldwide vegetation map units are qualitative terms described in the text. To estimate the cumulative presented branch area (5 cm or greater) for the qualitative map units, use was made of relations of calculated presented area versus stem diameter, derived from quantitative measurements (solid lines in Figure 25). These data (described in Reference 8) were computed from detailed vegetation data records, which defined the actual positions of all branches in three-dimensional space. Guided by the narrative description (Reference 10) of the mapped vegetation classes, cumulative relations of presented area versus branch diameter were positioned (dotted lines) in Figure 25 relative to the measured data. The estimated curves were used to determine the cumulative presented area for branch diameters of 5 cm and greater for all the vegetation map units (Reference 10) grouped as shown in Table 4.

It is emphasized that the interpretations at this point are tenuous because the vegetation maps show what vegetation should be at a location if not modified by cultural activities such as agriculture and construction. Further, estimating quantitative relations from qualitative descriptions is always subject to error. Nevertheless, it is well known that vegetation branches do deflect the trajectories of projectiles significantly, and the estimates of presented area for stem diameters of 5 cm and greater shown in Figure 25 and Table 4 appear reasonable for the various vegetation assemblages. No method is readily available to estimate how much of each mapped unit is not covered by the designated vegetation assemblages. For this analysis it was assumed that the vegetation occurred as mapped, and therefore the effects of vegetation will be somewhat less than actually indicated.

To use the data in Table 4 to arrive at the probability that the mine will be emplaced successfully, the presented area (of branches 5 cm and greater) in percentage of the total area is assumed identical to the probability of successful emplacement. For example, the sample map in Figure 24 shows that the southernmost portion of Africa contains vegetation that is predominantly cape sclerophyllous scrub. By referring to the legend for vegetation map units (map unit H in Table 4), it is found that vegetation of this type will have an 80 percent presented cumulative area of branch diameter of 5 cm or greater. Therefore, a mine deployed at random in this assemblage would probably strike branch diameters of 5 cm or greater 80 percent of the time. For this reason, the probability of successful emplacement would also be 80 percent.

The estimate of cumulative presented area is based on the mine going into the assemblage at an impact angle of 90 degrees. Therefore, if the soil in this area would permit excessive penetration of a Gator mine at a probable impact velocity (55 meters per second), the probability of suitable mine deployment in this area would still be 80 percent because the velocity would be degraded by the vegetation.

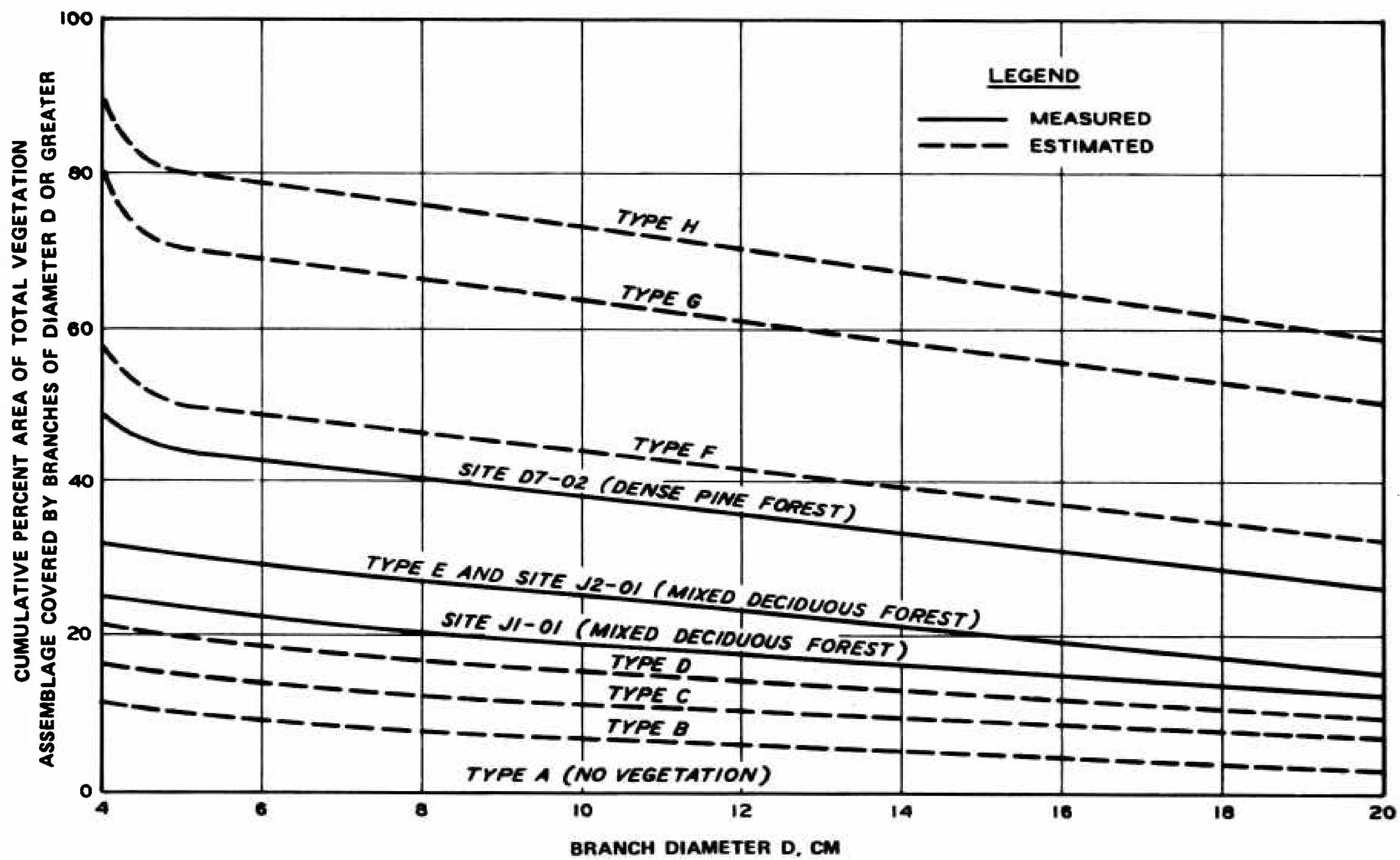


Figure 25. Estimated Cumulative Presented Area Versus Branch Diameter Relations

TABLE 4. LEGEND FOR VEGETATION MAP UNITS

Map Unit	Percent Probability[a]	Vegetation Types (Reference 9)
A	0	Bare ground; desert; semi-desert scrub; semi-desert scrub with desert grass; desert alternating with porcupine grass.
B	5	Tundra and alpine vegetation; 'forest steppe'; Australian sclerophyllous savanna; broad leaved tree savanna; microphyllous tree-desert grass savanna; microphyllous tree-tall grass savanna.
C	15	Blanket bog alternating with deciduous forest; blanket bog alternating with mixed forest; Australian sclerophyllous forest; microphyllous forest and woodland.
D	20	Sclerophyllous scrub with desert grass.
E	30	Deciduous summer forest; mixed southern pine and deciduous forest; southern pine forest; tropical seasonal forest.
F	50	Boreal forest dominated by larch; mixed boreal and deciduous forest; mixed lake and deciduous forest; broadleaved evergreen forest; evergreen mixed forest.
G	70	Mixed boreal and lake forest; mixed lake boreal and deciduous forest.
H	80	Tropical rain forest; tropical montane forest; tropical rain forest with conifers; sclerophyllous scrub; boreal, subalpine, and montane coniferous forest; coast and lake forest.

[a]Estimated presented area in percentage of branch diameters of 5 cm and greater.

The cumulative area presented to the mine entering the assemblage will increase as the impact angle decreases. This effect is believed to be less than the errors introduced by the assumption that an entire map unit is covered by the designated vegetation assemblage, but the errors are compensating. For this reason, in computing the total effect of soil strength and vegetation on the probability of effective emplacement of the Gator mine, the angle at which the mine enters the vegetation assemblage is ignored.

c. Computation of Probability of Successful Mine Emplacement Based on Soil Strength and Vegetation

Once the probability of successful emplacement of the mine is known for an area based on the individual effects of the soil strength and vegetation characteristics, a simple mathematical expression can be used to obtain the combined effect of these two terrain characteristics. This expression is:

$$P = V + (1 - V) S$$

where

P = probability of successful emplacement in a unit area based on soil strength and vegetation (decimal)

V = probability of successful emplacement in a unit area based on vegetation type (decimal)

S = probability of successful emplacement in a unit area based on soil strength characteristics (decimal).

For example, consider map unit 1 of the soil strength map (Figure 13). The probability of successful emplacement based on soil strength was computed to be 67 percent. The probability of successful emplacement based on vegetation (Figure 14) was determined to be 80 percent. Consequently, the combined probability of effective emplacement is 0.80 + 0.67(0.20) = 0.934. In other words, 80 percent of the time a mine will strike a vegetation stem, and 20 percent of the time the impact velocity of the mine will not be degraded. When the mine does impact the soil at full velocity, 67 percent of the time the soil will be firm enough to allow effective emplacement of the mine.

2. WORLDWIDE PERFORMANCE

To estimate the probability of satisfactory emplacement (for impact velocity of 55 meters per second and impact angle of 45 degrees) of the Gator mine worldwide, a factor complex map was produced in which the soil strength map (Reference 7) was used as a base and the vegetation conditions (Reference 10) were superimposed. This factor complex map shows the distribution of various terrain combinations from which a specific probability of successful penetration performance of the Gator mine was calculated by the procedures discussed above. Each area was designated by an indentification number. Also, the percent probability of successful emplacement performance was indicated in each area.

At the outset of the study it was hoped that the distribution, frequency of occurrence, and areal extent of the factor complex map units showing discrete classes of percent probability of satisfactory emplacement of the Gator mine would evolve from the study. The map discussed above shows the distribution of the factor complex map units, and the frequency of occurrence of the map units has been tabulated. The areas of the map units have not been determined because of time and funding constraints.

On the factor complex map the world is divided into 1390 map units (patches). For each patch a probability of satisfactory emplacement was computed. These computed values were grouped according to the successful emplacement performance probability classification for areas trafficable by heavy vehicles, as shown below.

Successful Emplacement Performance Probability for Trafficable Areas	Number of Mapped Occurrences	Percentage of Total Occurrences
100 to 80	630	45
80 to 60	290	21
60 to 40	134	10
40 to 20	187	13
20 to 0	149	11

The above results are of somewhat limited use because the individual map units do not have the same areas. To determine the percentage of the world's area that will permit successful emplacement of the Gator mine, the area of each mapped patch would have to be determined, and the areas would have to be grouped according to satisfactory emplacement probability.

3. SUMMARY

The tabulation above shows that successful emplacement of the Gator mine could be made in many areas of the world that are trafficable by heavy tracked vehicles. (The percentage of the world in which deployment of the mine would not be needed because of untrafficable soil conditions is approximately 4 percent.) However, many areas also occur in which the mine would not be emplaced successfully. Considering the fact that the tabulation is based on the mine entering the vegetation canopy at an impact angle of 45 degrees or less and impact at velocities of 55 meters per second or less, it becomes clear that even in this delivery mode the mine will often pass through the vegetation and penetrate to below the ground surface. If the mine is delivered at an impact angle of 90 degrees, excessive penetration is likely in bare soil if the cone index is less than 750. The fact should also be considered that the mine will almost always be delivered at impact angles between 45 and 90 degrees. This means that the probability of successful emplacement performance of the mine as related to the world's soil strength conditions will be even lower than that calculated herein. Consequently, the total effect of both soil strength and vegetation at this increased delivery angle will reduce the probability of successful emplacement performance to a greater degree than that shown in the tabulation. From this it becomes clear that an earth-clearing charge is needed to remove soil from the surface of the mine prior to its detonation.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

a. Based on the theoretical results presented herein, the following qualitative conclusions are drawn:

(1) The penetration resulting from an impact angle of 90 degrees of the Gator mine into firm target materials, typified by frozen sandy gravel, clay shale, and low-strength rock at velocities of 15 to 92 meters per second is small enough to be judged not excessive as far as the emplacement of the mine is concerned. In fact, in materials such as those studied, the mine will probably roll out of the impact crater, and therefore, the penetration will not be a factor in the functioning of the mine.

(2) For an impact angle of 90 degrees into soft soils, such as the clay and sandy clay targets used in this study, the penetration of the Gator mine would be excessive at all but the lowest impact velocities.

(3) For an impact angle of 90 degrees, penetration of the Gator mine in the sand soils is judged to be intermediate between excessive and nonexcessive at the medium to high impact velocities.

(4) The highest deceleration values are found for the low-strength rock terrain materials and for impact on the 14.6- by 14.6-cm mine surface.

b. Based on the field tests presented herein, the following conclusions have been drawn:

(1) At a 90-degree impact angle, penetration is excessive over the range of velocities tested (49 to 77 meters per second) for the wet lean and fat clays studied. Penetration is also excessive in 23 out of 40 tests for dry lean clay (moisture content = 15 percent) over the same velocity range. The initial depth of penetration (i. e., the depth of penetration reached prior to mine roll out) increases as the soil strength decreases. A trafficability cone index of at least 750 is required to ensure that excessive penetration will not occur when the mine impacts at a velocity of 55 meters per second (Figure 11).

(2) In general, penetration performance of the Gator mine becomes less satisfactory as the impact angle increases because of deeper penetration and the mine's tendency to stay in the impact crater. If the mine strikes the ground at an impact angle of 45 degrees, satisfactory emplacement can be expected in soils with strength greater than a trafficability cone index of 150 (Figure 11).

c. Based on the study of world surface soil strength and vegetation conditions, it is concluded that:

(1) Many surface soils of the world have strength less than a cone index of 750, and therefore, unsatisfactory mine emplacement will occur often if the mine is delivered at an impact angle of 90 degrees with an impact velocity of 55 meters per second.

(2) Many surface soils and vegetation conditions will permit satisfactory emplacement if the mine is delivered at an impact angle less than 45 degrees and with an impact velocity of less than 55 meters per second. However, many unsatisfactory emplacements can also be expected to occur.

2. RECOMMENDATIONS

Because the overall emplacement performance of the Gator mine appears to be less than required to ensure that the deployed mine will not be covered with soil, it is tentatively recommended that an earth-clearing charge be incorporated into the mine. In addition, since in a significant number of tests in which the mine bounced out of the impact crater the at-rest angle was 90 degrees, it is recommended that the cross-sectional shape be changed so that the mine cannot stand on edge.

The impact condition revealed that penetration can be expected to be a problem in many terrain materials. Because only a limited number of conditions were used, it cannot be positively stated how mine penetration can be reduced in all field deployment conditions. For this reason, it is recommended that further theoretical and experimental studies be conducted to define more adequately the emplacement performance of the Gator mine in world terrains. The theoretical study should be directed toward better determining the effect of impact angle (other than normal) on mine penetration; whereas, the experimental studies should be conducted to determine:

(1) Distribution of impact angles and attitudes of mines under prototype testing (i. e., actual dispensing of mines from an aircraft).

(2) How well an air gun can be used to simulate impact angles and attitudes observed during prototype testing.

(3) How well the predicted penetration depths compare with depths obtained during prototype testing.

It is emphasized that the effect of angular rotation and angle of obliquity at impact on the depth of penetration is not well understood, but this important facet of the problem may be extremely site dependent. Therefore, it is recommended that in addition to prototype testing, additional field experiments be conducted wherein Gator mine projectiles are fired into the ground with the air gun. The gun can be moved quickly from site to site allowing a considerable amount of controlled data to be gathered on the dynamic properties of the mine-terrain interaction. These data will provide insight into how such terrain factors as surface roughness and vegetation affect the emplacement performance of the mine. From this insight, improved techniques for estimating emplacement performance on a worldwide basis can be derived.

It is further emphasized that all test sites should be characterized to provide all inputs to the theoretical penetration model. This involves obtaining soil samples from the impact areas and testing them in the laboratory under dynamic loadings and specified controlled boundary conditions. The results of the experimental program should then be compared with the theoretically predicted penetration depths for the same terrain materials and impact velocities to assess the accuracy of the penetration model.

Additional tests should be performed in a wide variety of vegetation assemblages to define the decrease in depth of penetration due to (a) the decrease in velocity from impacting vegetation structures above the soil surface, and (b) the increase in soil strength due to the network of vegetation structure at and beneath the soil surface. These data should be analyzed to develop a more rigorous method of determining the influence of vegetation on the probability of suitable penetration performance.

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RADC (Mr Webb)	1
DDR&E (OSD/Asst Dir for T&E)	1
DDR&E (Land Warfare/Lt Col Landry)	1
EARI (Mr Johnson)	1

DA (DAEN-ZS)	1
DA (DAEN-MCZ-S)	1
DA (DAEN-RD)	1
DA (DAEN-FEP)	1
USAEC (AMSEL-NV-D/Mr Doepel)	1
USAME R&D Ctr (Mr Peters)	1
USATDC (INCSISD-B/Lt Col Hunter)	1
USAETL (ETL-CS-G/Mr Kotre)	1
USACRR&E Lab (CRREL-EM/Mr Crory)	1
USAME R&D Ctr (STSFB-XS/Mr Wallen)	1
USAME R&D Ctr (STSFB-X/Mr Kirkland)	1
USAT&DC (INCSTED-A/Maj Johnson)	1
USAATC (Tech Lib)	1
USAATC (STEAC-MT-MI/Lt Kennedy)	1
USA Yuma Prov Grd (Tech Lib)	1
USATTC (Dr Dobbins)	1
USAT&EC (AMSTE-TS-M/Mr Wise)	1
USA T-A Cmd (AMSTA-RGD/Dr Parks)	3
RMBSS (AMCPM-RBS-P/Mr Bernstein)	1
USAEC (AMSEL-NL-D/Mr Walker)	1
USAEC (AMSEL-TL-MF/Dr Hafner)	1
USAEC (AMSEL-PL-SA/Mr Sizelove)	1
USAEPG (STEEP-PP-M/Mr Jay)	1
USATTC (Mr Davis)	1
USAAC (R&D Directorate)	1
USALWL (RDLW-ADP/Mr Stevenson)	1
RMBSS (AMCPM-RBS-P/Col Cottey)	1
RMBSS (AMCPM-SMO-T/Mr Dennis)	1
USAEC (AMSEL-CT-S/Mr Schoening)	1
USAEC (AMSEL-TL-P/Mr Linden)	1
USAEC (AMSEL-CT-1/Mr Zarin)	1
USAEC (AMSEL-WL-V/Mr Cohen)	1
USAEC (AMSEL-NL-R-1/Mr Herring)	1
Selected Ammo, AMC (AMCPM-SA5)	1
USAAC&E Brd (STEBF-TO-CE/ Maj Gronich)	1
334 Eng Detachment (Maj Gates)	1
USAMC (AMCRD-01/Mr Blodgett)	1
USAMC (AMCDL-O/Mr Bender)	1
DA (DAMO)	1
DA (DARD-DD/Dr Garbert)	1
USAEC (AMSEL-CT-D)	1
USAEC (AMSEL-NL-R-2/Mr Klein)	1
USAIC (FORSIC) Library	1
USA Fld Artillery Board Tech Lib	1
Project MASSYER (Dr Dickinson)	1
USAMC (AMCPM-SMQ/Mr Barton)	1
TAWC (TRADOCLO)	1

INITIAL DISTRIBUTION (Concluded)

ADTC (SD)	1
ADTC (SD3)	4
AFATL (DLMM)	10
AFATL (DLY)	1
AFATL (DLJ)	1
AFATL (DLOSL)	2
AFATL (DL)	1
TAWC (TEFA)	1